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Mitigating the Impact of Intergenerational Risk Factors on Stunting: Insights From Seven of the Most Food Insecure Districts in South Africa

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ABSTRACT

A large body of research investigates the determinants of stunting in young children, but few studies have considered which factors are the most important predictors of stunting. We examined the relative importance of predictors of height-for-age *z*-scores (HAZ) and stunting among children under 5 years of age in seven of the most food-insecure districts in South Africa using data from the Grow Great Community Stunting Survey of 2022. We used dominance analysis and variable importance measures from conditional random forest models to assess the relative importance of predictors. We found that intergenerational and socio-economic factors—specifically maternal height (HAZ: Coef. 0.02, 95% CI 0.01–0.03; stunting: OR 0.96, 95% CI 0.94–0.98), birth weight (HAZ: Coef. 0.3, 95% CI 0.16–0.43; stunting: OR 0.5, 95% CI 0.35–0.72) and asset-based measures of socioeconomic status (HAZ: Coef. 0.17, 95% CI 0.10–0.24; stunting: OR 0.77, 95% CI 0.67–0.89)—were the most important predictors of HAZ and stunting in these districts. We explored whether any other factors moderated (weakened) the relationship between these intergenerational factors and child height using conditional inference trees and moderation analysis. We found that being on track for vitamin A and deworming, adequate sanitation, a diverse diet and good maternal mental health moderated the effect of birth weight or mother's height. Though impacts are likely to be small relative to the impact of intergenerational risk factors, these moderating factors may provide promising avenues for helping to mitigate the intergenerational transmission of stunting risk in South Africa.

1 | Introduction

Stunted linear growth in children impairs both cognitive and physical development, affecting health and economic potential (Black et al. 2013; World Health Organization 2015). A large body of research has investigated the risk factors and protective factors related to stunting (for a review focused on sub-Saharan Africa see Keino et al. 2014). The causes of stunting are complex and many of the predictors of stunting are intertwined or part of the same causal chain (Black et al. 2013; UNICEF 2020; World Health Organization 2016).

Stunting in children is the most prevalent form of malnutrition in South Africa (Modjadji and Madiba 2019). The most recent estimates suggest a stunting prevalence of 28.8% among children under five (Simelane et al. 2024). To address stunting and improve child health outcomes in South Africa, various national policies and strategic plans are in place, including the

Key messages

- Maternal height, birth weight and socioeconomic factors are the most important predictors of stunting in this sample.
- Several more easily modifiable factors—being on track for vitamin A and deworming, maternal alcohol use during pregnancy and adequate sanitation (particularly in urban areas)—are also important predictors of stunting in this sample.
- Being on track for vitamin A and deworming, adequate sanitation, a diverse diet and good maternal mental health moderate the effect of birth weight or mother's height, having a stronger association with height-for-age in children with lower birth weights and with shorter mothers. These factors may help to mitigate the intergenerational transmission of stunting risk.

Maternal, Perinatal and Neonatal Health Policy (2021), the National Integrated Early Childhood Development Policy (NIECD) (2015), the Maternal, Newborn, Child and Women's Health and Nutrition Strategic Plan (2012), the National Plan of Action for Children (2019–2024), the National Development Plan (2012) and the National Food and Nutrition Security Plan (2018–2023) (Sadan and Kotze 2024). These policies outline several interventions aimed at promoting healthy feeding practices and reducing malnutrition among children.

Key strategies include promoting and supporting exclusive breastfeeding for the first 6 months, along with appropriate complementary feeding practices to prevent both undernutrition and obesity. Additionally, micronutrient supplementation, such as folic acid and iron for pregnant women and vitamin A for infants and young children, is emphasised to address common deficiencies that contribute to stunting. Community- and facility-based growth monitoring is promoted to identify early signs of growth faltering to allow for timely referrals for follow-up care for children up to 2 years old (Republic of South Africa 2015). Food and nutritional support are also supposed to be provided to vulnerable pregnant women and young children through health facilities and community outreach workers. Screening for maternal and infant health issues, such as mental health, substance abuse and developmental delays, is integrated into ante- and postnatal care to address broader determinants of child health. The 'Road to Health' booklet is another tool that was developed to be used to empower parents and caregivers with information and encourage them to seek necessary health services (Republic of South Africa 2015), and the Child Support Grant (CSG) provides some financial assistance to households in need. However, these interventions face challenges such as inadequate funding, limited coordination among sectors and gaps in service delivery, which hinder their effectiveness in achieving meaningful reductions in child malnutrition and stunting.

Research indicates that in South Africa, stunting is closely linked to insufficient food intake, a lack of dietary diversity and poor nutritional knowledge (Burger et al. 2022). This connection is underscored by the broader context of food insecurity as a major factor in chronic malnutrition and stunting. In 2021, 15% of South Africa's then approximately 17.9 million households reported inadequate access to food, while 6% faced severe food shortages (Statistics South Africa 2021). According to the 2023 NFNSS, 83.3% of households with at least one child under 5 who is stunted experience food insecurity (Simelane et al. 2024). Additionally, the 2024 UNICEF Child Food Poverty report found that around 23% of children under 5 live in severe food poverty, defined as consuming only zero to two food groups out of a possible eight (UNICEF 2024).

While a range of risk factors have been found to be associated with stunting, only a handful of studies—from South Asia (Corsi, Mejía-Guevara, and Subramanian 2016; Kim et al. 2017, 2019; Svefors et al. 2019) and 35 low- and middle-income countries (LMICs) (Li et al. 2020)—have considered which of these factors are the most important predictors of stunting. Maternal height was consistently found to be the most important predictor of child stunting, followed by household wealth, maternal education and maternal BMI in varying order. Birth weight or length was also found to be one of the most important predictors of stunting in the studies that included it (Kim et al. 2019; Svefors et al. 2019).

Intergenerational factors are known to play a significant role in stunting. Parents—particularly mothers—who themselves had higher birth weights tend to have children with higher birth weights. Short mothers, who were more likely to have been stunted themselves as children, are more likely to have stunted children (Victora et al. 2008). Maternal size constrains foetal growth, and the effects of undernutrition in one generation persist across several generations (Martorell and Zongrone 2012). But some research suggests that the effect of intergenerational factors can be weakened by a healthy growth environment. Mothers who were malnourished in childhood can give birth to children of nearly normal size when they are exposed to substantially improved nutrition and healthier environments before conception, for instance, through immigration from a less developed to more developed country (Martorell and Zongrone 2012). Furthermore, when children are in socioeconomic environments favourable to growth, where care and nutrition are in line with international recommendations, their predicted adult heights are more likely to be normal (in line with those of children in developed countries) even if their parents experienced poor health and nutrition in childhood (Garza et al. 2013). These results suggest that favourable care and socioeconomic environments may dampen the intergenerational transmission of stunting risk.[1]

In this paper, we investigated which factors are the most important predictors of height-for-age *z*-scores (HAZ) and stunting among children under 5 years of age in seven of the most food-insecure districts in South Africa using data from the Grow Great Community Stunting Survey. Given that intergenerational and socioeconomic factors were the most important predictors of stunting, we examined what may moderate (weaken) the relationship between these factors and child height, using conditional inference trees and moderation analysis. These moderating factors may provide promising avenues for mitigating the intergenerational transmission of stunting risk in South Africa.

2 | Data

The Grow Great Community Stunting Survey was conducted in 2022 in seven of the most food-insecure districts in South Africa: ZF Mgcawu (Northern Cape), Thabo Mofutsanyane

(Free State), uMgungundlovu (KwaZulu Natal), Bojanala (North West), West Rand (Gauteng), Ehlanzeni (Mpumalanga) and Mopani (Limpopo). One district was selected from each of the nine South African provinces, excluding the Western Cape and Eastern Cape. Districts were identified based on their inclusion in the list of 32 most food-vulnerable districts in South Africa according to the National Food and Nutrition Security Plan 2018–2023 (Republic of South Africa 2017).

2.1 | Sampling and Data Collection

The Grow Great Community Stunting Survey aimed to assess the prevalence and drivers of stunting among children under 5 across seven food-vulnerable districts in South Africa. The survey was conducted by Grow Great in partnership with ikapadata. Ethics approval for the primary data collection was obtained from the University of Cape Town Ethics Committee (REF: REC 2020/01/011) and from the Stellenbosch University Social, Behavioural and Education Research Ethics Committee (REF: ECO-2024-29986) for the secondary analysis reported in this paper.

Data collection took place between February and May 2022. In recruiting fieldworkers preference was given to fieldworkers with experience in taking anthropometric measurements of young children, who had a nursing background, or who had worked with ikapadata (the organisation that conducted the fieldwork) previously. Fieldworkers received 4 days of training, including on taking anthropometric measurements, and were evaluated in the field before final selection (for more detail, see Grow Great Campaign 2023).

The sample consisted of 3221 children aged 0–59 months. Data were collected on a range of household and caregiver characteristics using a stratified multistage cluster sampling design. Survey characteristics were taken into account in analyses that allowed for survey adjustments using Stata's *svy* commands. Probability weights (the inverse of the probability of enumerator area selection multiplied by the inverse of the probability of household selection) were used to adjust for differing probabilities of being selected in the sample. To reduce the effect of extreme probability weights resulting from some enumerator areas where few households were successfully sampled, the probability weights were trimmed to the median weight plus four times the interquartile range (i.e., weights above that cutoff were replaced with the cutoff value). The conditional inference trees and conditional random forests did not allow for survey adjustments.

A third of children had missing values on one or more of the covariates and so could not be included in the analysis. Nonetheless, the final sample size of 2122 was still fairly large, and the characteristics of the full and estimation samples did not differ markedly.

2.2 | Variable Definitions

The key outcomes of interest are continuous HAZ and a binary variable indicating whether the child was stunted. We used both HAZ and an indicator for stunting because even children who are not classified as stunted may still experience linear growth faltering (Leroy and Frongillo 2019; Perumal, Bassani, and Roth 2018). Furthermore, there is no biological basis for the minus two standard deviations cutoff; risks associated with low height-for-age increase linearly with decreasing height-for-age (de Onis and Branca 2016; Perumal, Bassani, and Roth 2018). Examining a binary indicator also discards much of the variation contained in a continuous measure.

HAZ was created based on the WHO Child Growth Standards (de Onis and WHO Multicentre Growth Reference Study Group 2006) and adjusted for gestational age. Children were defined as stunted if their height was more than two standard deviations below the WHO Child Growth Standards median for their age and gender.

Age categories were created based on the child's age in completed months. As HAZ tends to decline rapidly up to 24 months and then plateau (Victora et al. 2010), the following categories were created: 0–5, 6–11, 12–17, 18–23, 24–35, 36–47 and 48–59 months.

Mother's education was categorised into three levels: less than matric (equivalent to completed secondary), matric or tertiary. The household head was defined as employed if they were working for pay or self-employed.

We opted to use an asset index rather than household income as a measure of household socioeconomic status (SES) for two reasons. First, there are missing values on household income for 384 children in the sample, while only two children had missing values for household asset ownership. Second, asset indices are also commonly used in place of household income or expenditure in surveys in LMICs where data collected on income and expenditure can be unreliable, for example, in the DHS (Filmer and Pritchett 2001; Filmer and Scott 2012). The asset index was constructed from a list of durable assets using multiple correspondence analysis (MCA). MCA is more appropriate than principal components analysis when dealing with binary indicator (dummy) variables (Booysen et al. 2008).

Access to adequate sanitation was defined as having a flush toilet, a ventilated pit toilet or a portable toilet in line with the definition of improved sanitation used by Statistics South Africa in the General Household Survey (Statistics South Africa 2021).

Children were defined as on track for vitamin A supplementation and deworming if they had received the required number of vitamin A and Mebendazole doses for their age. Being on track with vitamin A supplementation and deworming were highly correlated (> 0.8), so they were combined into one variable reflecting whether the child was on track for both vitamin A supplementation and deworming. As children are only scheduled to receive vitamin A supplementation from 6 months and deworming from 12 months, all children under 6 months were classified as being on track. As a robustness check, we excluded children under 6 months from the regressions, but the results did not change materially.

The child's mother was classified as having good mental health if she answered ‘no’ to all three mental health questions: whether she had thoughts and plans to harm herself or commit suicide, whether she felt down, depressed or hopeless and whether she felt unable to stop worrying or thinking too much.

The child was defined as having a diverse diet if their caregiver reported that the child consumed foods from five or more food groups out of a list of eight in the past 24 h, based on the WHO infant and young child feeding practices (IYCF) minimum dietary diversity indicator (World Health Organization 2010). This indicator was originally intended for children aged 6–23 months, but it was constructed for all children here as a proxy for dietary diversity.

The indicator for whether the child was exclusively breastfed until 6 months of age was based on whether the mother or caregiver reported that the child received anything other than breastmilk for the first 6 months.

Children were defined as small for gestational age (SGA) if their birth weight was below the 10th percentile of the INTERGROWTH-21st standard for their gestational age (Villar et al. 2014), calculated using the user-written *sgaIntergrowth* command in Stata.

2.3 | Data Cleaning

Five observations had birth weights below 500 g but were not born premature. These were deemed to have been incorrectly recorded as measured in grams, and these birth weights were multiplied by 10 to get birth weight in kilograms. Mother's height and BMI were winsorized at the first and 99th percentiles to deal with extreme values that are likely due to measurement error. Children with a HAZ above 4 or below −4 were excluded from the data set due to concerns that more extreme values may be due to measurement error.

3 | Methods

3.1 | Predictors of Stunting

We examined the predictors of HAZ using linear regression and the predictors of stunting using logistic regression. A multilevel modelling approach was considered, but given that most of the variation in child height was within rather than between districts, we opted for simpler linear and logistic regressions including district fixed effects. Unless otherwise noted, all analyses were conducted in Stata version 17.

Alderman and Headey (2018) show that many predictors of stunting have cumulative effects, so their effects may be underestimated by including children younger than 24 months. In light of this, in a supplementary analysis, we tested whether predictors of height-for-age differed for children under 24 months versus children 24 months and above by interacting all variables with an indicator for being 24 months or older. To explore whether predictors differed between urban and rural areas, we also ran the HAZ regressions separately for urban and rural areas.

3.2 | Relative Importance of Predictors of Stunting

We used two methods to examine variable importance: dominance analysis and machine learning variable importance measures from conditional random forests.

Dominance analysis assesses the relative importance of predictors in a regression based on their contribution to a model fit statistic, most commonly R^2 (Azen and Budescu 2003; Luchman 2021). We report general dominance statistics, representing the variable's average contribution to the explained variance across multiple models containing all possible combinations of the independent variables (Luchman 2021). This accounts for the fact that, in a single model, the order in which variables are added to the model will affect each variable's contribution to the explained variance. Dominance analysis assumes that variable selection has already occurred so that the variables in the model have nontrivial contributions to the explained variance (Luchman 2021). We therefore removed variables that were not significant in the linear regressions before conducting dominance analysis. Dominance analysis was conducted using the *domin* community-contributed command in Stata (Luchman 2021).

Conditional random forests are an ensemble machine learning algorithm based on conditional inference trees, a type of recursive partitioning model embedded in a conditional inference framework (Hothorn, Hornik, and Zeileis 2006). Conditional inference trees counter the tendency of traditional regression trees to favour splits on variables with many possible splits or missing values. Random forests grow many individual trees, randomly resampling both the observations and the set of predictors for each tree. Random forests tend to have greater predictive accuracy than individual regression trees, as they are less sensitive to overfitting random variations in the data. The conditional random forests were fit using the *partykit* package (Hothorn and Zeileis 2015) in R version 4.3.1. We used 1000 trees for each random forest. The importance of predictors in conditional random forest models is calculated based on permutation importance (Hapfelmeier et al. 2014). Random forests involve random sampling and are therefore subject to random variation. Variable importance and rankings may change slightly in different iterations of the algorithm based on different starting values and should thus be interpreted as a guide rather than an absolute ranking.

3.3 | Moderation Analysis

To explore whether modifiable factors moderated the effect of intergenerational factors, we used a conditional inference tree, as described above, and linear regressions where each intergenerational factor was interacted with a set of modifiable factors.

Regression trees are useful for detecting interactions, particularly complex interactions that may not be picked up by a linear regression. The minimum number of observations in each terminal node of the conditional inference tree was set to 200.

We explored variables that moderate mother's height, birth weight and the asset index, as these were the most important predictors in the relative importance analysis. For simplicity, separate regressions were run for each of these intergenerational or socioeconomic factors while controlling for the others, that is, in the first regression, mother's height is interacted with each potential moderator while controlling for birth weight and the asset index, and so on. We considered being on track with vitamin A and deworming, adequate sanitation, dietary diversity, good maternal mental health, exclusive breastfeeding, cooking using electricity/solar and whether the mother drank alcohol during pregnancy as potential moderators, as they could be targeted by policies or interventions in the short to medium term.

4 | Results

4.1 | Descriptive Statistics

Table 1 summarises potential predictors of stunting considered in this study for the estimation sample, testing for a difference in the means of these variables across stunted and nonstunted children (i.e., differences in proportions in the case of binary variables).

Stunted children were more likely to be male (difference 8.4 percentage points (p.p.); *p* value 0.010) and to be aged 12–35 months. Stunted children had lower birth weights (−0.227 kg; *p* value < 0.001) and were more likely to have been born SGA (15.1 p.p.; *p* value < 0.001). Their mothers were on average shorter (−2.330 cm; *p* value < 0.001) with a lower BMI (−1.732 units; *p* value < 0.001).

Stunted children lived in households with a lower average asset index, and their mothers tended to have lower levels of education. Mothers of stunted children were 7.6 percentage points less likely to have finished school (Grade 12) (*p* value 0.021). Mothers of stunted children were more likely to have drunk alcohol during their pregnancy with the child (5.7 p.p.; *p* value 0.016). Stunted children were less likely to be on track with vitamin A and deworming (−10.1 p.p.; *p* value 0.002).

Caregivers of stunted children were more likely to report that the child was breastfed exclusively until 6 months (6.6 p.p.; *p* value 0.043; see Section 5 for possible explanations for this). Differences in the means of the remaining variables were not significant.

4.2 | Predictors of Stunting

The regression results are available in Table 2. Male children had higher odds of being stunted (odds ratio (OR) 1.53, 95% CI 1.21–1.94), though the difference in HAZ was not significant. Mother's education was not associated with stunting, but children whose mothers had completed Grade 12 (the final year of school) had a higher HAZ than those with less than Grade 12 (significant only at the 10% level). Adequate sanitation was associated with higher HAZ, but only at the 10% level.

The mother's characteristics and factors determined during pregnancy—namely the child's birth weight (HAZ: Coef. 0.3, 95% CI 0.16–0.43; stunting: OR 0.5, 95% CI 0.35–0.72), mother's height (HAZ: Coef. 0.02, 95% CI 0.01–0.03; stunting: OR 0.96, 95% CI 0.94–0.98), mother's BMI (HAZ: Coef. 0.01, 95% CI 0.00–0.02; stunting: OR 0.98, 95% CI 0.96–1.00) and whether the mother drank alcohol during pregnancy (HAZ: Coef. −0.31, 95% CI −0.54 to −0.08; stunting: OR 1.72, 95% CI 1.08–2.72)—were all significantly related to HAZ and stunting in the expected directions. The household asset index (HAZ: Coef. 0.17, 95% CI 0.10–0.24; stunting: OR 0.77, 95% CI 0.67–0.89), being in an urban area (HAZ: Coef. 0.21, 95% CI 0.03–0.38; stunting: OR 0.67, 95% CI 0.46–0.99), and the child being on track with vitamin A supplementation and deworming (HAZ: Coef. 0.22, 95% CI 0.08–0.36; stunting: OR 0.73, 95% CI 0.54–0.98) were associated with higher HAZ and a lower probability of stunting.

Household size, whether the child was the firstborn, adequate water, whether the household head was employed, whether the mother had good mental health, whether the mother was a teenager when the child was born, the indicator for having a diverse diet and cooking fuel type were not significantly associated with HAZ or stunting.

With the exception of being on track for vitamin A and deworming, which had smaller effects for older children, the predictors of HAZ did not differ significantly between children under 24 months versus children 24 months or older (Supporting Information S1: Table S4). In the HAZ regressions stratified by urban residence (Supporting Information S1: Table S3), adequate sanitation and maternal education were significantly associated with HAZ in urban but not in rural areas. Good maternal mental health was significant in rural but not urban areas.

It is noted that the R^2 was very low in estimating both HAZ and stunting; most of the variance in child HAZ was not explained by any of the observed variables.

4.3 | Relative Importance of Predictors of Stunting

Figure 1 shows the variable importance rankings from the dominance analysis and conditional random forests. Though there are some differences in rankings between the dominance analysis and the conditional random forest variable importance, in both metrics of variable importance birth weight, mother's height, the asset index, and to a lesser extent mother's education emerged as the most important predictors of stunting. Child age and sex were also important predictors of stunting but were not considered further here as they reflect biological processes rather than factors that could be targeted by policy.

But some other factors (that may be more easily targetable by policy in the short term) were also important predictors of HAZ, including whether the child was on track with vitamin A supplementation and deworming and to a lesser extent whether the child's mother drank alcohol during pregnancy and whether the household had adequate sanitation.

4.4 | Moderators of Intergenerational Risk Factors

The conditional inference tree in Figure 2 gives a first indication that more modifiable factors, in this case being on track with vitamin A and deworming, may moderate the effect of intergenerational factors such as birth weight and mother's

TABLE 1 | Sample characteristics for stunted and nonstunted children.

Variable	(1) Total Mean/(SE)	(2) Not stunted Mean/(SE)	(3) Stunted Mean/(SE)	(2)–(3) Pairwise *t* test *p* value
Height-for-age *z*-score	−0.775	−0.369	−2.616	0.000***
	(0.035)	(0.033)	(0.026)	
Male	0.515	0.500	0.583	0.010***
	(0.013)	(0.014)	(0.029)	
0–5 months	0.109	0.122	0.048	0.000***
	(0.008)	(0.009)	(0.012)	
6–11 months	0.107	0.106	0.112	0.738
	(0.008)	(0.009)	(0.018)	
12–17 months	0.129	0.121	0.165	0.073*
	(0.009)	(0.009)	(0.023)	
18–23 months	0.124	0.116	0.159	0.068*
	(0.009)	(0.009)	(0.022)	
24–35 months	0.225	0.216	0.266	0.087*
	(0.011)	(0.012)	(0.027)	
36–47 months	0.163	0.163	0.161	0.939
	(0.009)	(0.010)	(0.022)	
48–59 months	0.144	0.156	0.089	0.000***
	(0.009)	(0.010)	(0.015)	
Birth weight (kg)	3.057	3.098	2.871	0.000***
	(0.014)	(0.015)	(0.029)	
Mother height (cm)	159.618	160.039	157.709	0.000***
	(0.180)	(0.199)	(0.416)	
Mother BMI	29.126	29.439	27.707	0.000***
	(0.196)	(0.220)	(0.413)	
Urban	0.578	0.587	0.538	0.127
	(0.012)	(0.013)	(0.029)	
Household size	4.373	4.338	4.534	0.117
	(0.047)	(0.052)	(0.114)	
Adequate water[a]	0.959	0.962	0.942	0.232
	(0.005)	(0.005)	(0.016)	
Adequate sanitation	0.553	0.559	0.524	0.292
	(0.013)	(0.014)	(0.030)	
Mother drank alcohol during pregnancy	0.089	0.078	0.136	0.016**
	(0.008)	(0.008)	(0.022)	
Asset index	−0.033	0.023	−0.289	0.000***
	(0.027)	(0.030)	(0.062)	
Firstborn	0.357	0.353	0.376	0.465
	(0.012)	(0.013)	(0.028)	
District: Bojanala (NW)	0.151	0.149	0.161	0.601
	(0.010)	(0.011)	(0.021)	
District: Ehlanzeni (MP)	0.159	0.161	0.150	0.674
	(0.010)	(0.011)	(0.024)	

(Continues)

TABLE 1 | (Continued)

Variable	(1) Total Mean/(SE)	(2) Not stunted Mean/(SE)	(3) Stunted Mean/(SE)	(2)–(3) Pairwise *t* test *p* value
District: Mopani (LP)	0.113	0.117	0.095	0.207
	(0.007)	(0.008)	(0.015)	
District: ZF Mgcawu (NC)	0.082	0.073	0.127	0.001***
	(0.006)	(0.006)	(0.016)	
District: Thabo Mofutsanyane (FS)	0.172	0.180	0.137	0.048**
	(0.009)	(0.010)	(0.019)	
District: uMgungundlovu (KZN)	0.203	0.197	0.228	0.308
	(0.011)	(0.012)	(0.028)	
District: West Rand (GP)	0.120	0.124	0.102	0.224
	(0.008)	(0.009)	(0.016)	
Mother has less than Grade 12	0.458	0.444	0.520	0.021**
	(0.013)	(0.014)	(0.030)	
Mother has Grade 12	0.439	0.445	0.413	0.321
	(0.013)	(0.014)	(0.029)	
Mother has tertiary education	0.104	0.112	0.068	0.011**
	(0.008)	(0.009)	(0.015)	
On track vit A and deworming	0.552	0.570	0.469	0.002***
	(0.013)	(0.014)	(0.030)	
Household head is employed	0.450	0.453	0.435	0.593
	(0.013)	(0.014)	(0.030)	
Mother has good mental health	0.896	0.898	0.888	0.644
	(0.008)	(0.009)	(0.019)	
Teen mother (at birth of child)	0.132	0.130	0.145	0.518
	(0.009)	(0.009)	(0.022)	
Diverse diet	0.211	0.214	0.195	0.428
	(0.010)	(0.011)	(0.022)	
Electricity/solar	0.851	0.855	0.834	0.407
	(0.009)	(0.010)	(0.023)	
Paraffin or gas	0.044	0.040	0.064	0.182
	(0.006)	(0.006)	(0.018)	
Solid	0.105	0.105	0.101	0.833
	(0.007)	(0.008)	(0.017)	
Exclusively breastfed until 6 months	0.532	0.520	0.586	0.043**
	(0.013)	(0.014)	(0.029)	
Small for gestational age	0.191	0.164	0.315	0.000***
	(0.010)	(0.010)	(0.027)	
Number of observations	2122	1730	392	

Note: Significance: ***0.01, **0.05, *0.1. Standard errors in parentheses.
Abbreviations: FS, Free State; GP, Gauteng; KZN, KwaZulu-Natal; LP, Limpopo; MP, Mpumalanga; NC, Northern Cape; NW, North West.
[a]Very few households had inadequate water, so this variable was not included in the regressions.

height. Being on track for vitamin A and deworming was associated with higher HAZ for children with lower birth weights and shorter mothers but not for those with higher birth weights and taller mothers. The algorithm split first on the asset index. Among less wealthy children, it then split on birth weight, and among more well-off children, it split on mother's height. For children with lower birth weights (≤ 3.14 kg, the split point chosen by the algorithm), it then

TABLE 2 | Linear regressions predicting HAZ and stunting.

	HAZ			Stunted		
	Coef.	95% CI	p value	OR	95% CI	p value
Male	−0.08	[−0.19,0.04]	0.182	1.53***	[1.21,1.94]	0.001
0–5 months (reference)		[0.00,0.00]	—	1	[1.00,1.00]	—
6–11 months	−0.16	[−0.50,0.18]	0.358	3.28***	[1.69,6.35]	0.000
12–17 months	−0.54***	[−0.85,−0.22]	0.001	4.21***	[2.31,7.66]	0.000
18–23 months	−0.73***	[−1.08,−0.38]	0.000	4.44***	[2.20,8.94]	0.000
24–35 months	−0.57***	[−0.85,−0.29]	0.000	3.36***	[1.83,6.15]	0.000
36–47 months	−0.51***	[−0.82,−0.20]	0.001	2.39**	[1.18,4.84]	0.016
48–59 months	−0.35**	[−0.63,−0.08]	0.011	1.4	[0.70,2.78]	0.341
Birth weight (kg)	0.30***	[0.16,0.43]	0.000	0.50***	[0.35,0.72]	0.000
Mother height (cm)	0.02***	[0.01,0.03]	0.000	0.96***	[0.94,0.98]	0.000
Mother BMI	0.01**	[0.00,0.02]	0.014	0.98**	[0.96,1.00]	0.019
Urban	0.21**	[0.03,0.38]	0.019	0.67**	[0.46,0.99]	0.043
Household size	−0.01	[−0.04,0.03]	0.670	1.05	[0.98,1.13]	0.142
Adequate sanitation	0.13*	[−0.01,0.28]	0.077	1.07	[0.74,1.56]	0.713
Mother drank alcohol during pregnancy	−0.31***	[−0.54,−0.08]	0.008	1.72**	[1.08,2.72]	0.022
Asset index	0.17***	[0.10,0.24]	0.000	0.77***	[0.67,0.89]	0.000
Firstborn	0.11	[−0.07,0.28]	0.229	1.12	[0.80,1.55]	0.510
Mother has less than Gr. 12 (reference)		[0.00,0.00]	—	1	[1.00,1.00]	—
Mother has Gr. 12	0.12*	[−0.01,0.24]	0.060	0.95	[0.70,1.30]	0.768
Mother has tertiary education	0.26	[−0.07,0.58]	0.123	0.81	[0.47,1.40]	0.450
On track vit A and deworming	0.22***	[0.08,0.36]	0.002	0.73**	[0.54,0.98]	0.037
Household head is employed	0.07	[−0.07,0.20]	0.322	1.06	[0.77,1.47]	0.702
Mother has good mental health	0.04	[−0.17,0.24]	0.737	1.06	[0.64,1.76]	0.820
Teen mother (at birth of child)	0.09	[−0.17,0.35]	0.502	0.82	[0.48,1.41]	0.480
Diverse diet	−0.13	[−0.34,0.08]	0.221	0.84	[0.56,1.28]	0.423
Electricity/solar (reference)		[0.00,0.00]	—	1	[1.00,1.00]	—
Paraffin or gas	−0.11	[−0.55,0.34]	0.635	1.44	[0.48,4.32]	0.510
Solid	0.03	[−0.22,0.28]	0.802	0.91	[0.51,1.61]	0.742
Exclusively breastfed until 6 months	−0.14*	[−0.30,0.02]	0.084	1.39*	[0.96,2.02]	0.081
Small for gestational age	−0.13	[−0.34,0.07]	0.190	1.26	[0.90,1.76]	0.179
Constant	−4.98***	[−6.59,−3.38]	0.000	252.50***	[6.91,9224.77]	0.003
Observations	2122			2122		
R^2	0.155					

Note: Controls for district included but not displayed.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

split on being on track with vitamin A and deworming. Among poorer children with lower birth weights, children who were on track for vitamin A and deworming had higher mean HAZ—close to that for children with higher birth weights but short mothers. No significant split was found for the 'on track' variable for children with higher birth weights. Likewise, among richer children, a significant split was found for being on track with vitamin A and deworming only among children with shorter mothers (≤ 164 cm, the split point chosen by the algorithm) but not among those with taller mothers (> 164 cm).

Table 3 shows the results of the moderation analysis: linear regressions of HAZ, interacting each potential moderator with mother's height, birth weight and the asset index. The table presents the interactions of each potential moderator with mother's height in the second column, with birth weight in the third column, and with the asset index in the fourth column. In each case, '*X*' represents the variable in the column heading. For mother's height, the interactions with diverse diet (Coef. −0.02, 95% CI −0.04 to −0.00) and the mother having good mental health (Coef. −0.04, 95% CI −0.07 to −0.01) were negative and statistically significant at the 5% level, and adequate

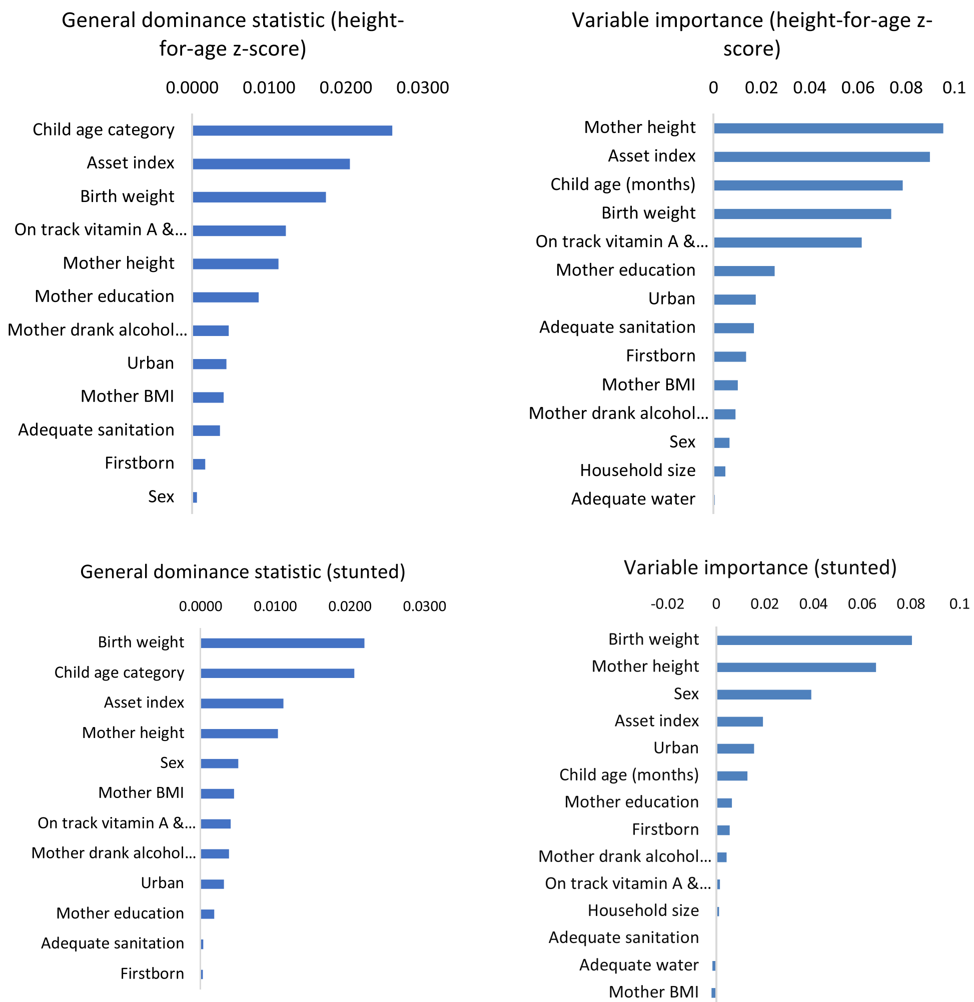

FIGURE 1 | Relative variable importance, HAZ and stunting.

sanitation at the 10% level. For birth weight, only the interaction with being on track with vitamin A supplementation and deworming was statistically significant (Coef. −0.41, 95% CI −0.68 to −0.14). For the asset index, none of the interaction terms were significant. All significant interactions were negative, as hypothesised, suggesting that these variables have a stronger association with HAZ for children with lower birth weights and shorter mothers. Put differently, mother's height and birth weight are less strongly associated with HAZ for children with these factors.

5 | Discussion

In line with studies from other countries, the general pattern that emerged from our analysis is that intergenerational and socioeconomic factors, namely maternal height, birth weight and asset-based measures of SES, were the most important predictors of HAZ and stunting in these seven districts. These results are in line with studies in India (Corsi, Mejía-Guevara, and Subramanian 2016; Kim et al. 2019), Bangladesh (Svefors et al. 2019) and 35 LMICs (Li et al. 2020), which also found that birth weight, maternal height, the household asset index and maternal education were among the most important predictors of stunting. Altering these factors with short-run policy levers is unlikely, particularly after the child is born. However, we found that being on track for vitamin A and deworming and alcohol use during pregnancy were also important predictors of stunting. These factors may be more easily modifiable through policy interventions. While they tend to be less important than maternal height, birth weight or SES, being on track for vitamin A and deworming, maternal alcohol use during pregnancy and adequate sanitation (particularly in urban areas) rank fairly highly in the variable importance measures.

The age pattern of growth faltering in these districts was similar to that observed across countries (Karlsson et al. 2023; Leroy et al. 2014; Victora et al. 2010) and illustrated in Supporting Information S1: Figure S1: HAZ declined from birth to 18–23 months and then increased slightly; stunting rates increased and then declined.

Given the benefits associated with breastfeeding and exclusive breastfeeding, such as reducing child mortality (Black et al. 2013) and protecting against infections (Victora et al. 2016), the negative coefficient on exclusive breastfeeding (though only significant at the 10% level) may initially seem contrary to expectations. However, the handful of randomised controlled trials and systematic reviews of breastfeeding promotion and longer exclusive breastfeeding duration found no

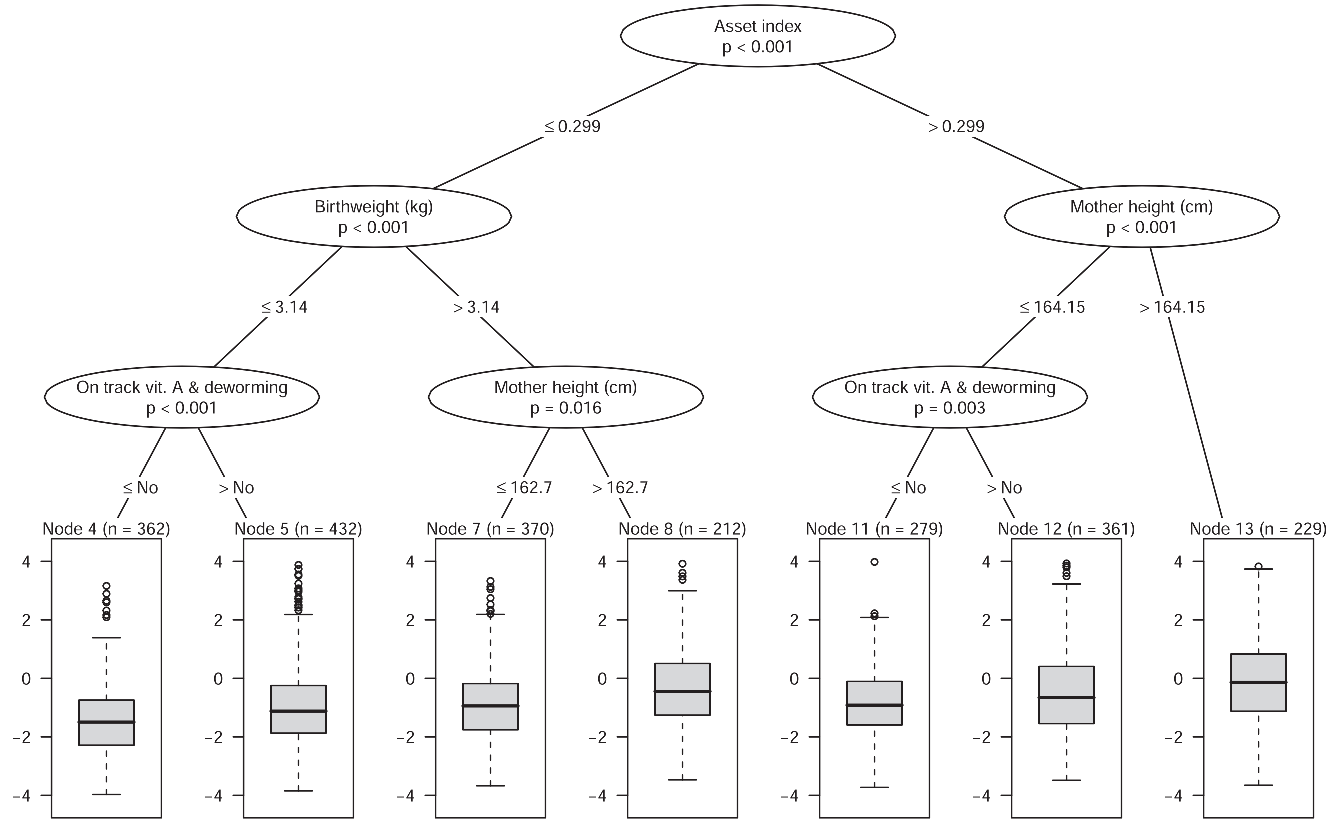

FIGURE 2 | Conditional inference tree for HAZ.

effects on child length (Black et al. 2013; Kramer and Kakuma 2012; Kramer et al. 2007). The accuracy of reported exclusive breastfeeding may also be affected by recall bias, social desirability bias or varying understandings of what exclusive breastfeeding entails. Furthermore, the relationship between breastfeeding and child growth may be confounded by SES (Victora et al. 1991), as higher-socioeconomic-status mothers may be less likely to breastfeed exclusively. Supplementary analyses presented in Supporting Information S1: Table S2 suggest that in this sample children reported to have been exclusively breastfed came from households with lower household income, and their caregivers were less likely to be employed. In a supplementary analysis reported in Supporting Information S1: Table S1, we found that exclusive breastfeeding was positively associated with HAZ among children under 6 months but became negatively associated with HAZ thereafter. The rates of exclusive breastfeeding reported are also suspiciously high. In this sample, 53% of children were reported to have been exclusively breastfed up to 6 months; rates of exclusive breastfeeding among children under 6 months in the DHS were only 32% (Department of Health 2019). These results suggest that recall bias and confounding by SES may both have been at play in this data set.

We found that being on track for vitamin A and deworming, adequate sanitation, a diverse diet and good maternal mental health moderated the effect of birth weight or mother's height, having a stronger association with HAZ in children with lower birth weights and with shorter mothers. These more modifiable factors may thus contribute to mitigating the intergenerational transmission of stunting risk.

A diverse diet in recommended amounts ensures that children receive adequate nutrients essential for growth, potentially offsetting the effects of low birth weight or maternal height on stunting by improving postnatal nutritional status of the child. For example, inadequate dietary diversity and suboptimal complementary feeding are directly linked to stunting, particularly in the first 2 years of life (Black et al. 2013; Lassi et al. 2020; Stewart et al. 2013).

Moreover, maternal mental health can influence caregiving practices and feeding behaviours. Depression among mothers has been linked to higher rates of diarrhoea, respiratory disease, lower completion of recommended immunisation schedules, stunting and hospital admissions, among others (World Health Organization 2018). Local studies have found that food insecurity among women is linked to poorer mental health and a smaller likelihood of breastfeeding (Matlwa Mabaso et al. 2022; Sayed et al. 2022).

Being on track for vitamin A supplementation, especially in populations where micronutrient deficiencies are prevalent due to food insecurity, along with regular deworming, which reduces micronutrient deficiencies and parasite burdens, are important for preventing stunting. Deficiencies in nutrients such as vitamin A and zinc, along with untreated parasitic infections, can suppress growth by reducing appetite, impairing nutrient absorption and increasing nutrient losses (Black et al. 2013; Dewey and Begum 2011).

Water, hygiene and sanitation (WASH) factors, such as unimproved sanitation and access to water, are another leading

TABLE 3 | HAZ estimations including interactions between intergenerational risk factors and potential moderators.

	(1) X = Mother height Coef.	95% CI	(2) X = Birth weight Coef.	95% CI	(3) X = Asset index Coef.	95% CI
Mother height (cm)	0.06**	[0.01,0.10]	0.02***	[0.01,0.03]	0.02***	[0.01,0.03]
Birth weight (kg)	0.29***	[0.16,0.42]	0.94***	[0.31,1.57]	0.30***	[0.17,0.43]
Asset index	0.16***	[0.09,0.23]	0.17***	[0.10,0.24]	0.06	[−0.35,0.47]
6–11 months	−0.18	[−0.52,0.15]	−0.16	[−0.49,0.18]	−0.12	[−0.48,0.23]
12–17 months	−0.56***	[−0.88,−0.24]	−0.53***	[−0.85,−0.21]	−0.52***	[−0.84,−0.19]
18–23 months	−0.71***	[−1.07,−0.36]	−0.71***	[−1.06,−0.36]	−0.71***	[−1.06,−0.37]
24–35 months	−0.57***	[−0.85,−0.28]	−0.54***	[−0.82,−0.25]	−0.56***	[−0.84,−0.27]
36–47 months	−0.51***	[−0.83,−0.20]	−0.50***	[−0.82,−0.19]	−0.51***	[−0.83,−0.19]
48–59 months	−0.34**	[−0.61,−0.07]	−0.33**	[−0.61,−0.05]	−0.34**	[−0.63,−0.06]
$X \times$ 6–11 months	0.05***	[0.02,0.09]	0.00	[−0.57,0.58]	0.18	[−0.12,0.49]
$X \times$ 12–17 months	0.01	[−0.03,0.05]	−0.27	[−0.81,0.27]	0.16	[−0.18,0.50]
$X \times$ 18–23 months	0.01	[−0.02,0.05]	−0.63**	[−1.22,−0.04]	0.08	[−0.18,0.34]
$X \times$ 24–35 months	0.01	[−0.02,0.04]	−0.50**	[−0.99,−0.02]	0.09	[−0.14,0.33]
$X \times$ 36–47 months	0.03	[−0.01,0.06]	−0.27	[−0.86,0.31]	−0.06	[−0.35,0.22]
$X \times$ 48–59 months	0.00	[−0.03,0.03]	−0.38	[−0.90,0.14]	−0.03	[−0.27,0.21]
Mother drank alcohol during pregnancy	−0.30***	[−0.53,−0.07]	−0.31***	[−0.53,−0.09]	−0.35***	[−0.59,−0.11]
$X \times$ Mother drank alcohol during pregnancy	−0.01	[−0.04,0.02]	0.10	[−0.30,0.49]	−0.05	[−0.26,0.16]
On track vit A and deworming	0.21***	[0.08,0.35]	0.24***	[0.10,0.38]	0.22***	[0.08,0.36]
$X \times$ On track vit A and deworming	−0.01	[−0.02,0.01]	−0.41***	[−0.68,−0.14]	−0.07	[−0.23,0.09]
Adequate sanitation	0.14*	[−0.01,0.29]	0.12	[−0.03,0.26]	0.15**	[0.00,0.31]
$X \times$ Adequate sanitation	−0.02*	[−0.03,0.00]	−0.06	[−0.33,0.20]	0.08	[−0.05,0.21]
Diverse diet	−0.11	[−0.31,0.08]	−0.14	[−0.35,0.07]	−0.13	[−0.35,0.09]
$X \times$ Diverse diet	−0.02**	[−0.04,−0.00]	0.09	[−0.20,0.37]	0.05	[−0.13,0.23]
Mother has good mental health	0.05	[−0.16,0.25]	0.05	[−0.17,0.26]	0.04	[−0.17,0.25]
$X \times$ Mother has good mental health	−0.04**	[−0.07,−0.01]	0.06	[−0.33,0.44]	0.03	[−0.16,0.23]
Exclusively breastfed until 6 months	−0.14*	[−0.30,0.02]	−0.14*	[−0.30,0.02]	−0.14	[−0.30,0.03]
$X \times$ Exclusively breastfed until 6 months	−0.01	[−0.03,0.01]	−0.20	[−0.47,0.06]	0.11	[−0.05,0.26]
Household cooks using electricity/solar	0.02	[−0.24,0.28]	0.05	[−0.21,0.31]	−0.02	[−0.25,0.20]
$X \times$ Household cooks using electricity/solar	0.01	[−0.01,0.03]	−0.01	[−0.30,0.27]	−0.05	[−0.24,0.13]
Constant	−1.06***	[−1.54,−0.57]	−1.12***	[−1.60,−0.63]	−1.12***	[−1.61,−0.62]
Observations	2122		2122		2122	

Note: Other controls are included but not displayed.
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

correlate of stunting (Budge et al. 2019; Danaei et al. 2016; Richter et al. 2018). This can be attributed to many pathways, such as contamination of household and caregiver environments (hands, floors, animals) (Budge et al. 2019) leading to episodes of infection or diarrhoea, or environmental enteric dysfunction (EED) as a chronic condition which increases intestinal inflammation (Budge et al. 2019; Dewey and Begum 2011; Harper et al. 2018). Millward (2017) suggests that inflammation, often resulting from infection, EED and inadequate WASH, along with internal inflammation linked to adiposity, contributes to stunting.

The predictive effect on stunting of birth weight and alcohol use during pregnancy reiterates the importance of the first 1000 days of life—from conception to 2 years—for linear growth and development (Black, Pérez-Escamilla, and Fernandez Rao 2015; Victora et al. 2008, 2010). While much of the variation in birth weight is due to genetic factors (Lunde et al. 2007), birth weight is also influenced by maternal nutrition, health and environmental exposures during pregnancy and around the time of conception (Christian et al. 2015; Likhar and Patil 2022; Wrottesley, Lamper, and Pisa 2016). This underscores the need for screening and provision of nutritional and other support services for pregnant women.

The importance of maternal height underscores the need to intervene even before pregnancy to improve maternal outcomes to disrupt the cycle of intergenerational transmission of stunting. Improved nutrition during the first 1000 days of life is likely to improve outcomes for the next generation, but adolescence may be a further window of opportunity for intervention. Some catch-up growth appears possible during the adolescent growth spurt, which may in turn improve birth outcomes for the next generation (Arlinghaus et al. 2018; Das et al. 2018; Georgiadis and Penny 2017; Prendergast and Humphrey 2014; Prentice et al. 2013). The immediate preconception period is also a promising avenue for intervention (Mumford et al. 2014; Prendergast and Humphrey 2014).

The importance of SES as a predictor of HAZ highlights the importance of improvements to the broader socioeconomic environment—or nutrition-sensitive interventions (Ruel and Alderman 2013)—for improving stunting. Improvements in asset accumulation and female education were among the key contributors to reductions in stunting across countries over time (Bhutta et al. 2020; Headey 2013; Smith and Haddad 2015; Vaivada et al. 2020). Economic growth has also been found to facilitate reductions in stunting (Aiyar and Cummins 2021; Harttgen, Klasen, and Vollmer 2013; O'Connell and Smith 2016; Smith and Haddad 2015; Yaya et al. 2020). While there is some conflicting evidence (Headey 2013), improved sanitation also appears to have contributed to reductions in stunting (Smith and Haddad 2015; Vaivada et al. 2020). These findings suggest that large-scale reductions in stunting are unlikely to be achieved without broad improvements in socioeconomic conditions. The factors we identified as possible mitigators of intergenerational stunting risk are unlikely to lead to very large improvements on their own, even for children most at risk. Large-scale improvements will require long-term intergenerational improvements rather than policy-related mitigation measures.

5.1 | Limitations

This study has several limitations. First, it is based on cross-sectional data and can only show associations; we cannot conclude that any of the predictors cause linear growth faltering or stunting.

Many possible influences on stunting were not captured in our data or could not be measured fully. This is reflected in the relatively low proportion of the variation in HAZ and stunting explained by our models. Data were not collected on a number of factors that may affect child height, such as maternal smoking during pregnancy. Other variables that were captured showed little or no variation (e.g., antenatal care visits, respiratory illness or diarrhoea in the last 2 weeks) and so could not be included in the analysis. Given the difficulties in capturing all influences on child height, some variables we include may in part be picking up the effects of other unmeasured variables. For example, the variable capturing whether the child is on track with vitamin A supplementation and deworming may be picking up 'care' more broadly—whether the child has been taken to the clinic. This may in turn reflect other aspects of the responsiveness of caregiving.

Some variables included are blunt measures or poor proxies for the variable of interest. Our measure of dietary diversity was based on caregivers' recall of foods that the child was given in the previous 24 h, but dietary intake is prone to large day-to-day variations and measuring dietary intake based on 24-h recall is prone to error (Foster and Bradley 2018; Gibson, Charrondiere, and Bell 2017). The measure of maternal mental health is based on only three questions regarding the mother's mental health and is not a validated measure of mental health such as the Center for Epidemiologic Studies Depression Scale (CES-D) score.

Many variables were reported by the caregiver rather than measured directly and may be subject to measurement error or bias. Alcohol use during pregnancy and length of breastfeeding may be subject to social desirability or recall bias. If the extent of misreporting differs by other characteristics such as SES, this may in turn bias the results.

5.2 | Strengths

Though the Grow Great Community Stunting Survey was not nationally representative and was focused on seven districts, it has a relatively high sample size with complete HAZ measurements. It is a rich source of data on a range of variables associated with child health. As an important contribution, these data record gestational age, allowing HAZ to be adjusted for gestational age. As Supporting Information S1: Figure S1 shows, these data reveal that failing to adjust for gestational age results in underestimating HAZ (and therefore overestimating stunting), particularly at younger ages.

This is one of the few studies to assess the relative importance of predictors of stunting, and the only one of which we are aware from South Africa or SSA. It uses more sophisticated measures of variable importance than those used in most other studies, apart from Svefors et al. (2019), which also uses conditional random forest variable importance. It makes a new contribution in exploring potential moderators of intergenerational transmission of stunting risk.

6 | Conclusion

Linear growth faltering has a strong intergenerational component, but improving care and nutrition postbirth may help to mitigate intergenerational stunting risk somewhat. The most important predictors of HAZ and stunting in this sample were birth weight, maternal height and SES, as measured by an asset index. Being on track for vitamin A and deworming, adequate sanitation, a diverse diet and good maternal mental health moderated the effect of birth weight or mother's height, having a stronger association with HAZ in children with lower birth weights and with shorter mothers; these variables were most strongly associated with HAZ for children most at risk. Though impacts are likely to be small relative to the impact of intergenerational risk factors, these moderating factors may provide promising avenues for helping to mitigate the intergenerational transmission of stunting risk in South Africa.

Author Contributions

Kate Rich: conceptualization, methodology, formal analysis, writing–original draft. **Liezel Engelbrecht:** writing–original draft. **Gabrielle Wills:** conceptualization, writing–review and editing, supervision, project administration. **Edzani Mphaphuli:** writing–review and editing, funding acquisition, resources.

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Conflicts of Interest

Grow Great is a non-profit organisation involved in advocacy work to reduce stunting in South Africa. Kate Rich and Gabrielle Wills received financial support for the submitted work from Grow Great. Edzani Mphaphuli is the Executive Director of Grow Great, which commissioned this work. Grow Great was involved in the survey design and data collection and the decision to submit for publication but did not influence the methodology or analysis decisions. The funders of the Grow Great Community Stunting Survey were not involved in the analysis or interpretation of data. Liezel Engelbrecht is now employed by one of the funders of this work (the DG Murray Trust) but was an independent consultant when this work was completed.

Data Availability Statement

The data that support the findings of this study are available from Grow Great. Restrictions apply to the availability of these data for privacy reasons.

Endnotes

[1] A high correlation between parents' and children's heights is not necessarily a bad thing. The strongest associations between parental height and children's height are in high-income countries (Garza et al. 2013). When both generations were exposed to a healthy growth environment, genes were likely to be a stronger influence on growth (i.e., growth is less constrained by environmental factors), resulting in a higher correlation between parental height and children's height due to genetic factors. However, in an environment where many parents were malnourished as children, a weaker association between their height and their children's height may be a sign that their children's nutrition has improved relative to that of their parents in childhood and may signify a 'washing out' of intergenerational effects.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.