Recovery from stunting in early childhood and subsequent schooling outcomes: Evidence from NIDS Waves 1-5

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Abstract

This paper explores the association between catch-up growth in early childhood and subsequent educational outcomes, using data from the first five waves of NIDS conducted between 2008 and 2017. While an extensive literature documents the negative effects of early stunting (a commonly-used marker of undernutrition) on children's developmental potential, there is far less evidence on whether a recovery from stunting in early childhood - or 'catch-up growth' - helps to mitigate the negative effects of early growth retardation. This study shows that, on average, children who recovered from stunting between 2 and 4/5 years of age still go on to complete fewer years of schooling compared to their non-stunted counterparts. This seems to be driven in large part by a slower progression through the schooling system once enrolled. However, there also appear to be heterogeneous effects depending on the extent of recovery; the small proportion of children who recovered such that their height fell within the 'normal' range for their age at follow-up, exhibit similar educational outcomes to the non-stunted group. These results have important implications for the timing of nutritional investments in the early childhood period.

1. Introduction

Poor nutrition in early childhood, typically measured by stunting (or low height-for-age), is a massive public health concern in developing countries, with evidence of negative consequences for cognitive function, educational attainment and productivity (Hoddinott *et al*. 2008; Victora *et al* 2008; Dewey and Begum 2011). There has been much focus on the importance of the first 1000 days in particular (from conception to the second birthday), as this is a period of rapid growth and neurological development. Nutritional insults over this 'window of opportunity' therefore may have long-term consequences for cognitive function and other developmental outcomes (Morgan and Gibson 1991; Shonkoff *et al* 2012; Black *et al* 2013).

There is growing evidence for South Africa that stunted children do worse than other children on a variety of outcomes. Casale, Desmond and Richter (2014) used data from a cohort study of children born in 1990 in Johannesburg (Birth to Twenty) to show that children who were stunted at 2 years scored significantly lower on cognitive tests at the age of 5 compared to their non-stunted counterparts. Based on data from the KwaZulu-Natal Income Dynamics Survey from 1993-2004, Yamauchi (2008) showed that pre-school-aged children with lower height-for-age z-scores had poorer subsequent schooling outcomes. Consistent with these findings, Casale (2016) using the more recent National Income Dynamics Study (NIDS), showed that stunting among children (under the age of 8) in Wave 1 (2008) was related to lower educational attainment by Wave 4 (2014-15), partly because stunted children were enrolled in school later, but mostly because they were less likely to pass the grades they had enrolled for.

While the negative effects of early stunting are well-documented, the question remains as to whether subsequent catch-up growth among stunted children can help to ameliorate the negative consequences of early linear growth retardation. Evidence suggests that in developing countries the rate of growth in infants falters after birth, with height relative to the healthy reference population (according to WHO height-for-age standards) continuing to decline until around the age of two, after which there is a levelling-off or even some recovery (Stein *et al* 2010; Victora *et al* 2010; Prentice *et al* 2013). Indeed, for South Africa, there is evidence of substantial catch-up growth among stunted children both from the early birth cohort data and from the first waves of NIDS (Casale 2016; Desmond and Casale 2017). However, there are mixed findings in the literature as to whether this subsequent growth, typically measured as a recovery from stunting, helps to mitigate the negative effects of early stunting.

Using the Young Lives (YL) data from Peru, Crookston *et al* (2010) report that children who recovered from stunting between baseline (6-18 months) and follow-up (4.5-6 years) had better cognitive test scores at follow-up compared to children who remained stunted, and similar scores to those were never stunted. In later work, Crookston *et al* (2013) used YL data from Ethiopia, India, Peru, and Vietnam to show that children who recovered from stunting between 6-18 months and 7-8 years had better educational and cognitive outcomes than children who remained stunted. Georgiadis *et al* (2017) use the same multi-country data to show that post-infancy recovery from stunting is associated with better achievement scores at 8 and 12 years. These authors argue that while preventing stunting is important, consideration should also be given to nutritional interventions in the post-1000 day period. Other studies have reported less promising results. Mendez and Adair (1999) found that children in the Philippines who recover from stunting between 2y and 8y/11y do worse at school than children who were never stunted, although less so than those who remain stunted. Casale and Desmond (2016), using the 1990 Birth to Twenty Cohort data from Johannesburg, showed that children who recovered from stunting between 2 and 5 years still did worse than their non-stunted counterparts on cognitive tests as 5 years, and almost as badly as children who remained stunted.[1]

Investigating this issue is important as it has implications for the *timing* of investments in early childhood, and would shed some light on whether the first 1000 days are ‘critical’ for the child’s cognitive development, or whether there is room for remediation (Cunha and Heckman 2007). An important point to make from the outset, though, is that even if catch-up growth after 2 years is found not to be associated with better cognitive function, improved growth among young children is important in its own right and may have other benefits (for example, preventing children from falling further behind, or better reproductive health outcomes among girls in later

[1] Although they do not use recovery from stunting to identify catch-up growth, the work by Glewwe and King (2001) on the Philippines is relevant. They explore the effect of growth in cm at various stages between 0 and 8 years and conclude that the 18-24 month period is the most important for subsequent cognitive function.

life). However, if children who catch up in height after 2 years are still found to fare poorly in certain areas, such as cognitive function or educational achievement, then renewed policy focus on preventing stunting in the first place is crucial if all children are to be given the chance to develop to their full potential.

This paper explores the relationship between catch-up growth in early childhood and subsequent educational outcomes using data from the first five waves of NIDS covering the period 2008 to 2017. More specifically, the educational outcomes of children who recovered from stunting between 2 and 4/5 years of age are compared to those of children who remained stunted and who were never stunted. The *extent* of catch-up growth among children who recovered from stunting is also analysed, with a view to testing whether children who caught up by more have different outcomes. While the definitions of catch up and the age ranges used in Casale and Desmond (2016) are replicated as closely as possible in this paper to allow for comparison, unlike the Birth to Twenty cohort study, NIDS does not contain direct information on early cognitive function. Nonetheless, the extensive information on schooling outcomes is instructive, and allows us to examine whether differences in educational attainment are being driven by non-enrolment, delayed enrolment, or slow progression through the schooling system.

The regression results suggest that, even after controlling for individual- and household-level observable characteristics, children who recovered from stunting in early childhood still go on to complete fewer years of schooling than their non-stunted counterparts, largely because of higher failure rates and therefore a slower progression through the schooling system. However the extent of catch-up growth appears to matter; although the majority of children who recovered from stunting recorded poorer educational outcomes, the small proportion of children who recovered such that their height might be considered to be in the ‘normal’ range for their age at follow-up exhibited very similar outcomes to the children who were never stunted. The significance of these findings will be discussed in the final section of the paper.

Before continuing, it is important to highlight the two main limitations of the work. First, the sample size is relatively small because of the specific age range analysed in early childhood, and because of the requirement that children be in at least three waves of the study (with non-missing data on anthropometric and educational outcomes). Second, while an extensive set of observable characteristics is controlled for in the regression analysis, there may be unobserved household- or individual-level heterogeneity which limits the identification of causality. Again, the implications for the results will be discussed in more detail in the final discussion section. The next section (Section 2) describes the data, the sample and the definitions used in the analysis, while Section 3 presents the estimation results.

2. Data and sample

To explore the association between catch-up growth and subsequent educational outcomes, data are drawn from the first five waves of NIDS conducted between 2008 and 2017. To measure catch-up growth in early childhood, the child's stunting status is used, stunting defined as a height-for-age Z score (HAZ) less than two standard deviations below the median of the healthy reference population according to WHO standards.[2] Stunting is the most commonly-used indicator of longer-term undernutrition among children, and although the literature on catch-up growth is sparse, a recovery from stunting is generally used to measure subsequent catch up (Adair 1999; Mendez and Adair 1999; Crookston *et al* 2010; 2013; Casale and Desmond 2016; Georgiadis *et al* 2017). There has been some recent debate in the public health literature as to whether recovery from stunting is too weak a definition of catch up (Cameron et al 2005; Lundeen et al 2014; Leroy et al 2015; Desmond and Casale 2017).[3] Therefore to test whether a

[2] For children up to the age of five years, the z-scores were calculated using the WHO international child growth standards (WHO 2006), and for children older than five years, the WHO growth standards for school-aged children and adolescents were used as the reference (de Onis *et al* 2007). The NIDS data are pre-cleaned, with biologically implausible values set to missing following WHO guidelines (further detail can be found in de Villiers *et al* 2013: 30-32).

[3] One of the key issues is whether changes in HAZ over time should be used to define catch-up growth. HAZ is calculated as the cm difference between the index child's height and the (age and sex-appropriate) reference population median height, divided by the standard deviation. Because the standard deviation increases with age, it is possible that a child's cm height deficit can remain the same over time, while the HAZ increases. Some authors have suggested that the cm gap should at least decline for catch-up to be considered meaningful. Another issue is that children close to the -2 HAZ cut-off for stunting will be more likely to be classified as 'caught-up' at follow-up than those further away from the threshold. Desmond and Casale (2017) apply a range of definitions to the Birth to Twenty cohort data and find that the rates of catch up vary substantially depending on definition. The strictest

stricter definition of catch up would produce different results, a second definition is used, where children are required not only to have recovered from stunting (HAZ >-2) but also to have passed the HAZ > -1 threshold into the 'normal' HAZ range (Desmond and Casale 2017).[4]

The age range over which catch-up growth is measured also requires careful consideration, and must take into account the typical pattern of growth identified in many developing countries over the early childhood period. Using data from both population-level surveys and cohort studies, research has shown that height-for-age z-scores fall off soon after birth and continue to decline until around 2 years of age, after which they either level off or increase (Stein *et al* 2010; Victora *et al* 2010; Prentice *et al* 2013). The prevalence of stunting (HAZ <-2) therefore tends to increase between birth and 2 years, reaching a peak somewhere between 24-36 months. If the starting point in the measurement of catch up is taken too early, before the prevalence of stunting has reached a peak, then a number of children could be identified as not stunted at baseline even though they might still become stunted by the end of the second year.[5]

The starting point (t_1) used in this study is 2 years, i.e. 24-36 months, and the age at first follow-up (t_2) is 4/5 years. While the age at follow-up was determined by the spacing between the waves in NIDS, conveniently this age range is very similar to that used in the work by Casale *et al* based on the early cohort data, allowing for some comparison of the results (Casale and Desmond 2016; Desmond and Casale 2017; Casale *et al* 2018). To maximise the number of observations for the analysis, the sample consists of children who were 2 years old in either Waves 1, 2 or 3, and who were observed again in the subsequent wave (Wave 2, 3 or 4) when they were 4 or 5 years old.

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definition used was a recovery from stunting with HAZ at follow up >-1; all children who recovered to this extent also exhibited a reduction in the cm height deficit.

[4] This definition has been applied previously, where the rationale is that under a normal distribution, 15.87% of the population would fall below the -1 HAZ cut-off (Wang and Chen 2012).

[5] Casale *et al* (2018) show how varying the starting point from which catch-up growth is measured from 2 years to 1 year substantially affects rates of catch-up growth as well as the association between catch-up growth and cognitive function in 5 year olds. Indeed, this is likely to be part of the reason for why mixed results have been identified in the literature; many of the studies rely on data from the Young Lives surveys, where data were collected on children who were 6-18 months at baseline.

Based on the HAZ information from the first two time points (t_1 and t_2), children are classified as:

1. not stunted at either t_1 or t_2 (the reference category)
2. stunted at both t_1 and t_2
3. caught up between t_1 and t_2, i.e. stunted at t_1 at 2 years, but not stunted at t_2 at 4/5 years
   - 3.1 catch up 'incomplete', i.e. HAZ at t_2 < -1
   - 3.2 catch up 'complete', i.e. HAZ at t_2 >= -1
4. late incident stunted, i.e. not stunted at t_1, but stunted at t_2.

We are most interested in the children in category 3, as we want to test whether children who 'caught up', or recovered from stunting, in early childhood, have different educational outcomes from those who were never stunted (category 1) and from those who remained stunted (category 2). This allows us to identify whether timing matters, namely whether the first 1000 days or so of growth are the most important for later developmental outcomes. To explore whether the extent of catch up matters, category 3 is also split into two additional groups: 3.1) children who recovered from stunting by t_2 but HAZ at t_2 was still less than -1, and 3.2) children who recovered from stunting by t_2 and HAZ at t_2 was greater than or equal to -1, i.e. they had crossed over into a 'normal' HAZ range. The terms 'incomplete' and 'complete' catch up are used very loosely here for convenience, but of course these classifications are, to a certain degree, based on arbitrary thresholds. Nonetheless, this split goes some way to addressing the concern that a simple recovery from stunting (HAZ >-2) by t_2 may be too weak a definition of catch up.

The educational outcomes of these categories of children are then analysed when they are observed again in Wave 5 (t_3). There were 945 children who had non-missing data on HAZ at t_1 and t_2, and of these, 840 or 89% were re-interviewed in t_3, i.e. in Wave 5.[6] Table 1 summarises

[6] Unfortunately, the sample size is limited because of high rates of missing data on HAZ in some of the waves. Of children aged 6 months to14 years, a valid HAZ was captured for 77% in Wave 1, 55% in Wave 2, 82% in Wave 3 and 90% in Wave 4. This issue is compounded by general attrition between waves because the children also needed to be interviewed in the subsequent wave for catch up to be measured. Of the 668 two-year-olds in Wave 1, 68% have a HAZ value in Wave 1 and 51% have a HAZ value in Wave 2. Of the 794 two-year-olds in Wave 2, 43% have

this information (the table should be read across the rows). In brief, there are three samples of two year-olds from Waves 1, 2 and 3, who are observed again in the subsequent wave and also re-interviewed in Wave 5. This means that while catch-up growth is measured over roughly the same age range (2 - 4/5 years) for all children in the analytical sample[7], their educational outcomes are captured at different ages ranging from 6 to 12 years in 2017. This needs to be accounted for in the regression analysis, and considered in the choice of outcome variables.

Table 1. Sample of children with non-missing data on HAZ at t_1 and t_2 who were re-interviewed in Wave 5

	W1 2008	**W2** 2010/11	**W3** 2012	**W4** 2014/15	**W5** 2017	**N**
2 year-olds in W1	t_1=2y	t_2=4/5y			t_3=10/11/12y	211
2 year-olds in W2		t_1=2y	t_2=4/5y		t_3=8/9/10y	177
2 year-olds in W3			t_1=2y	t_2=4/5y	t_3=6/7/8y	452
Total						**840**

Five different educational outcomes are analysed, all based on data from the Wave 5 child questionnaire. The first outcome examined is the number of grades completed by 2017. A child may complete fewer grades of schooling compared to others of the same age because he/she was not enrolled in school, because he/she was enrolled later, or because he/she did not progress one grade per year. To explore these various mechanisms, three additional outcomes are analysed: enrolment, i.e. whether or not the child was enrolled in Grade 1 or higher in 2017; the age at first enrolment in Grade 1; and the outcome of the previous year, i.e. whether the child had passed or failed/withdrawn from the grade in 2016, conditional on attendance[8]. Failure in the previous year only provides a partial picture of progression though, so as a final summary measure, grade-for-age is also calculated, with children classified as young for their grade, the correct age for their grade, or old for their grade.

a HAZ value in Wave 2 and 74% have a HAZ value in Wave 3. And, of the 801 two-year olds in Wave 3, 79% have a HAZ value in Wave 3 and 80% have a HAZ value in Wave 4.

[7] Due to the shorter lag between Waves 2 and 3, 49 children from the Wave 2 sample of 2-year-olds were still either 2 years old (n=1) or 3 years old (n=48) in Wave 3. These children were excluded from the analysis so that catch up is measured over the same age range for all the children.

[8] For convenience, this variable is referred to as 'failed in 2016', as the vast majority of children who attended school in 2016 either passed or failed, with less than a quarter of a percent withdrawing before completing the year.

Children can start Grade 1 in South Africa at 5 and half years (if they are turning 6 by 30 June of their Grade 1 year) but they must be enrolled by the year in which they turn 7. All the children in our sample therefore should be in school when observed in Wave 5, with the youngest group of 6-year-olds (born in 2010) enrolled in Grade 1, and the oldest group of 12-year-olds (born in 2005) enrolled in Grade 6, if they started school in the year they turned 7 and progressed one grade per year. The youngest cohort of 6-year-olds would not be expected to have completed a grade by 2017, though, nor would they have an outcome for the 2016 school year, if they started school in the year they turn 7. The data indicate, however, that a large proportion of these children are enrolled in Grade 1 before this age, and therefore have values for these outcome variables. A decision was taken to leave them in the main sample to maximise the sample size. Nonetheless, as a robustness check, the regressions are also rerun excluding the children who were aged 6 in Wave 5, which reduces the sample by 111 observations.

In estimating the association between stunting status and subsequent educational outcomes, a range of controls are included the regressions. Most important among these are the age variables which take into account the varying ages at which children are captured in t_3/Wave 5, and are included as a set of dummies for each year of age from 6 to 12 years. In addition, the child's age in months at t_1 and t_2 are included to account for the fact that the period over which catch-up growth is measured between 2 and 4/5 years will also vary slightly due to different birth and interview dates. A set of dummy variables - 'Wave 1 sample', 'Wave 2 sample', and 'Wave 3 sample'- indicate the cohort of two-year-olds the child is in.

The other controls include dummies for African, female, urban, and province of residence, as well as a set of variables capturing socio-economic status and the home environment, specifically, the log of per capita household income, whether a grant is received on behalf of the child, whether the mother is deceased, mother's schooling, and the number of child aged 0-14 in the household. Because of the relatively large number of missing values on mother's schooling (6% of the 840 children), a dummy variable indicating mother's education was missing is added. All of these control variables are based on data from Wave 5.

Table 2 contains the summary statistics for the sample of children with non-missing data on HAZ at t_1 and t_2 who were also re-interviewed in Wave 5. There are generally low rates of missing values on the outcome and control variables. One important exception is the age at first enrolment in Grade 1. This is not because children were not enrolled (enrolment rates in Grade 1 or above are very high for the sample, at 97%) but because of a large number of system missing values and 'Don't know' responses in the Wave 5 data. The estimations using this variable, therefore, must be treated with some caution.

The distribution of children across stunting status is noteworthy. Just under 62% of children in the sample were not stunted at t_1 or t_2, a further 12% were stunted at both t_1 and t_2, 7% became stunted between t_1 and t_2, and 19% had recovered from stunting by t_2.[9] Of this latter group of children who recovered from stunting in early childhood, the majority (68% or 110/162 children) did not exhibit a 'complete catch up', with only 32% (52/162 children) catching up to the degree that HAZ at t_2 had reached or surpassed the -1 'normal' threshold.

The similarity in these rates of catch up to those found in Casale *et al* (2018) is remarkable given that their work is based on data from an urban birth cohort from 1990. They found that 18% of their sample of children recovered from stunting between 2 and 5 years, and that similarly the majority of these children (70%) did not exhibit 'complete catch up' (also defined as HAZ >= -1 at 5 years). The distribution of their sample across the other categories is not as close to the NIDS distribution, but nonetheless within a fair range; 76% of their sample of children was not stunted at 2 or 5 years, 5% was stunted at 2 and 5 years, and just less than 2% could be classified as late incident stunted. The larger proportion of children who were not stunted in early childhood in the Birth to Twenty data could, in part, be attributed to the fact that their sample consisted of children living in the largest metropolitan area in SA, and the prevalence of stunting in urban areas is lower than in rural areas.

[9] The prevalence of stunting at age 2 for this sample of 840 children (drawn from the first three waves) is 31.3%. This is very close to the 32.4% prevalence recorded in 2008 using the full sample of 2-year-olds from the first wave who had data on HAZ (n=454), i.e. the sample unaffected by attrition.

Table 2. Summary statistics

Variable	N	t	Mean (Std. Dev.) or %
Outcome variables			
No. of grades completed	838	t_3	2.01 (1.78)
Enrolled in Gr 1 or higher	839	t_3	97.38%
Age first enrolled	603	t_3	5.50 (0.86)
Failed in 2016	827	t_3	5.56%
Old for grade	837	t_3	15.53%
Correct age for grade	837	t_3	55.79%
Young for age	837	t_3	28.67%
Stunting status			
Not stunted in t_1 and t_2	840	t_1 and t_2	61.67%
Stunted in t_1 and t_2`	840	t_1 and t_2	12.02%
Catch up by t_2	840	t_1 and t_2	19.28%
--Complete catch up (HAZ < -1)	840	t_1 and t_2	6.19%
--Incomplete catch up (HAZ >= -1)	840	t_1 and t_2	13.10%
Late incident stunted	840	t_1 and t_2	7.02%
Control variables			
Age 6 (omitted)	840	t_3	13.21%
Age 7	840	t_3	38.81%
Age 8	840	t_3	6.90%
Age 9	840	t_3	15.83%
Age 10	840	t_3	1.43%
Age 11	840	t_3	19.17%
Age 12	840	t_3	4.64%
W1 sample (omitted)	840	t_1	25.12%
W2 sample	840	t_1	21.07%
W3 sample	840	t_1	53.81%
Age in months at t_1	840	t_1	30.36 (3.37)
Age in months at t_2	840	t_2	59.02 (4.94)
African	840	t_3	88.10%
Female	840	t_3	53.21%
Ln(per capita hh income)	840	t_3	6.78 (0.81)
Grant received for index child	837	t_3	84.95%
No. of children under 15y in hh	840	t_3	3.31 (2.20)
Mom deceased	837	t_3	5.62%
Mom schooling (years)	786	t_3	10.16 (2.91)
Mom schooling missing	840	t_3	6.43%
Urban	840	t_3	42.14%
Western Cape (omitted)	840	t_3	7.26%
Eastern Cape	840	t_3	11.43%
Northern Cape	840	t_3	6.19%
Free State	840	t_3	5.60%
KwaZulu-Natal	840	t_3	38.45%
Northwest	840	t_3	6.31%
Gauteng	840	t_3	8.10%
Mpumalanga	840	t_3	6.55%
Limpopo	840	t_3	10.12%

Note: The sample consists of children with non-missing data on HAZ at t_1 and t_2 who were re-interviewed in W5.

3. Estimation results

The first set of estimation results in Table 3 are from the regressions of educational outcomes on stunting status, where the weaker definition of catch up is used, i.e. a recovery from stunting by t_2. Regression I shows that children who were stunted in both t_1 and t_2 complete significantly fewer years of schooling compared to the reference category of children who were never stunted, with a coefficient of -0.279. This result is very similar to that in the study by Casale (2016) using NIDS data, where children (aged 0-8 years) who were stunted in Wave 1 were found to have completed 0.294 fewer years of schooling by Wave 4 (when they were 7-14 years old), compared to their non-stunted counterparts. In that study, this value fell marginally to 0.252 after controlling for unobserved household heterogeneity using a household fixed effects model. Of course the age ranges and time periods used here are different, and unfortunately controlling for household fixed effects is not possible with this small age-specific sample, but the similarity of the results is nonetheless reassuring.

Of particular interest in this study is the result for the group who caught up between t_1 and t_2. Despite having recovered from stunting between 2 and 4/5 years, these children still do significantly worse than those who were never stunted. The coefficient of -0.171 suggests that they don't do as badly as the children who remained stunted; however, the F test shown at the bottom of the table indicates that the difference between the coefficients (-0.279 and -0.171) is not significant. The 'late incident' group who became stunted between 2 and 4/5 years do no differently from those who were never stunted. These first set of results suggest that growth in the first 2 years is the most important for later developmental outcomes, with a recovery from stunting after 2 years producing only limited benefits in terms of schooling outcomes (although of course there may be other benefits to a child's recovery).

Regressions II-IV try to explore the various reasons for why some children complete fewer years of schooling. The children in the catch-up group are marginally less likely to be enrolled in 2017 compared to those who were never stunted, although this is only significant at the 10% level (Regression II). And they tend to start Grade 1 a bit later on average, although this result is not significant at conventional levels (Regression III). Also, as explained above, the sample size drops substantially for Regression III because of missing data on the age first enrolled in school so this result should be treated with caution. Regression IV indicates that both children who remained stunted and children in the catch-up group are significantly more likely to have failed the grade they were enrolled for in 2016 compared to children who were not stunted. Again, an F test indicates no significant difference between the coefficients (0.073 and 0.054) on the 'stunted' and 'catch-up' variables. The final regression (V) confirms that, compared to the not-stunted group, children who remained stunted and children who recovered from stunting progress more slowly through the schooling system, with children in these two categories significantly more likely to be old for their grade (as a opposed to young or the correct age for their grade). Table 4 shows the main results on stunting status when the youngest group of 6 year-olds in Wave 5 is excluded from the regression sample. The results are largely robust except that the coefficient for the catch up group in the 'failed in 2016' regression (Regression IV), while still positive, is no longer significant.

Table 3. Regression results using recovery from stunting definition of catch up (OLS coefficients)

	I	**II**	**III**	**IV**	**V**
	No. of grades completed	**Enrolled in Gr 1 or higher**	**Age first enrolled**	**Failed in 2016**	**Old for grade**
Stunted in t_1 and t_2	-0.279***	-0.020	0.072	0.073***	0.124***
	(0.071)	(0.018)	(0.109)	(0.025)	(0.038)
Catch up by t_2	-0.171***	-0.026*	0.031	0.054***	0.079***
	(0.058)	(0.015)	(0.090)	(0.021)	(0.031)
Late incident stunted	-0.054	-0.020	0.144	0.007	0.059
	(0.087)	(0.022)	(0.127)	(0.031)	(0.046)
Age 7	0.142*	-0.048**	0.336**	-0.042	-0.004
	(0.081)	(0.021)	(0.155)	(0.029)	(0.043)
Age 8	0.460**	-0.073	0.310	-0.008	-0.095
	(0.195)	(0.050)	(0.294)	(0.070)	(0.104)
Age 9	0.421*	-0.104*	0.374	-0.035	-0.045
	(0.240)	(0.062)	(0.352)	(0.086)	(0.127)
Age 10	-0.100	-0.057	-0.483	0.829***	0.605*
	(0.676)	(0.173)	(0.896)	(0.240)	(0.359)
Age 11	0.266	-0.066	-0.883	0.922***	0.781**
	(0.712)	(0.183)	(0.950)	(0.253)	(0.378)
Age 12	0.410	-0.059	-0.864	0.844***	0.761**
	(0.725)	(0.186)	(0.974)	(0.258)	(0.385)
W2 sample	-2.144***	0.011	-0.915	0.817***	0.668*
	(0.658)	(0.169)	(0.865)	(0.234)	(0.349)
W3 sample	-3.818***	-0.063	-1.295	0.916***	0.537
	(0.700)	(0.180)	(0.928)	(0.249)	(0.372)

Age in months at t_1	0.016	0.003	0.026	0.013***	0.016***
	(0.011)	(0.003)	(0.017)	(0.004)	(0.006)
Age in months at t_2	0.030***	-0.001	0.026*	-0.007**	0.003
	(0.009)	(0.002)	(0.014)	(0.003)	(0.005)
African	0.162*	0.015	0.088	0.023	-0.047
	(0.097)	(0.025)	(0.162)	(0.035)	(0.052)
Female	0.222***	0.013	-0.124*	-0.038**	-0.106***
	(0.044)	(0.011)	(0.068)	(0.016)	(0.023)
Ln(per capita hh income)	0.089***	0.005	-0.115**	-0.003	-0.020
	(0.033)	(0.008)	(0.051)	(0.012)	(0.018)
Grant received for index child	0.102	0.018	-0.264**	-0.008	0.027
	(0.068)	(0.018)	(0.105)	(0.025)	(0.036)
No. of children <15y in hh	0.012	-0.001	-0.032*	0.000	-0.006
	(0.011)	(0.003)	(0.017)	(0.004)	(0.006)
Mom deceased	-0.050	0.001	-0.207	0.031	-0.011
	(0.096)	(0.025)	(0.147)	(0.035)	(0.051)
Mom schooling (years)	0.029***	0.000	-0.012	-0.009***	-0.006
	(0.008)	(0.002)	(0.013)	(0.003)	(0.004)
Mom schooling missing	0.347***	-0.015	-0.170	-0.122***	-0.082
	(0.123)	(0.032)	(0.190)	(0.044)	(0.065)
Urban	-0.008	0.025	0.198**	0.009	0.041
	(0.060)	(0.015)	(0.092)	(0.022)	(0.032)
Eastern Cape	0.085	-0.063*	-0.187	0.043	0.133**
	(0.126)	(0.032)	(0.209)	(0.046)	(0.067)
Northern Cape	0.230*	-0.005	-0.391*	-0.006	-0.016
	(0.123)	(0.031)	(0.205)	(0.044)	(0.065)
Free State	0.194	-0.008	-0.274	0.077	0.027
	(0.143)	(0.037)	(0.232)	(0.051)	(0.076)
KwaZulu-Natal	0.296**	-0.028	-0.441**	0.067	0.017
	(0.122)	(0.031)	(0.201)	(0.044)	(0.065)
Northwest	0.270*	-0.022	-0.230	-0.005	0.050
	(0.144)	(0.037)	(0.228)	(0.052)	(0.076)
Gauteng	0.457***	-0.047	-0.416*	0.003	-0.014
	(0.136)	(0.035)	(0.216)	(0.049)	(0.072)
Mpumalanga	0.264*	-0.041	-0.321	0.018	0.030
	(0.145)	(0.037)	(0.237)	(0.052)	(0.077)
Limpopo	0.363***	0.011	-0.359	0.004	0.002
	(0.139)	(0.036)	(0.224)	(0.050)	(0.074)
Constant	0.592	0.980***	5.490***	-0.704**	-0.867**
	(0.780)	(0.200)	(1.083)	(0.278)	(0.414)
F test: Stunted in t_1 and t_2 = Catch up by t_2	1.80	0.10	0.11	0.42	1.12
Prob>F	0.178	0.7492	0.7439	0.5163	0.2911
N	834	835	601	824	833

Notes: Standard errors in parentheses. *** p<0.01 ** p<0.05 * p<0.10. Omitted categories are not stunted, Wave 1 sample, age 6, male, rural, Western Cape.

Table 4. Regression results using recovery from stunting definition of catch up, excluding children aged 6 in Wave 5 (OLS coefficients)

	I	II	III	IV	V
	No. of grades completed	**Enrolled in Gr 1 or higher**	**Age first enrolled**	**Failed in 2016**	**Old for grade**
Stunted in t_1 and t_2	-0.301***	-0.015	0.090	0.088***	0.142***
	(0.078)	(0.020)	(0.112)	(0.027)	(0.043)
Catch up by t_2	-0.185***	-0.033**	0.042	0.032	0.090**
	(0.064)	(0.017)	(0.096)	(0.022)	(0.035)
Late incident stunted	-0.058	-0.022	0.144	-0.002	0.074
	(0.096)	(0.025)	(0.133)	(0.033)	(0.053)
F test: Stunted in t_1 and t_2 = Catch up by t_2	1.70	0.60	0.14	3.43	1.11
Prob>F	0.1933	0.4385	0.7124	0.0646*	0.2929
N	723	724	561	714	722

Notes: Standard errors in parentheses. *** p<0.01 ** p<0.05 * p<0.10. Omitted category is not stunted. A full set of controls was included as in Table 3.

The next set of tables presents the results of the regressions when the stricter definition of catch up is used. The group of children who recovered between t_1 and t_2 are split into those with a HAZ at t_2 still below the -1 threshold – the 'incomplete catch up' group, and those with a HAZ at t_2 within the 'normal' range (HAZ >=-1) – the 'complete catch up' group. The estimates suggest the group of children who caught up completely do no differently on any of the educational measures from the group of children who were never stunted. In contrast, the children in the 'incomplete catch up' group do worse on all measures compared to the children who were never stunted (although the coefficient in the age first enrolled regression is not significant). There is also very little difference between the coefficients for this group of 'incomplete catch up' children and the group that remained stunted. F tests shown at the bottom of the table confirm that none of the differences in the coefficients between these two groups is significant. The results are robust to removing the youngest cohort of children who were 6 years old in Wave 5 from the sample (shown in Table 6).

Again, these results are similar to those found in Casale *et al* (2018) using the 1990 birth cohort data. They used five different definitions of catch up ranging from very weak to very strict, with the strictest definition based on the HAZ >=-1 threshold. They find that children who caught up generally scored lower on cognitive tests than children who were never stunted, except for the relatively small group of children who had recovered such that their HAZ at 5 years fell into the normal range.

Table 5. Regression results using stricter definition of catch up (HAZ >= -1 in t_2) (OLS coefficients)

	I	II	III	IV	V
	No. of grades completed	**Enrolled in Gr 1 or higher**	**Age first enrolled**	**Failed in 2016**	**Old for grade**
Stunted in t_1 and t_2	-0.280***	-0.020	0.071	0.074***	0.125***
	(0.071)	(0.018)	(0.109)	(0.025)	(0.038)
Complete catch up (HAZ < -1)	-0.031	-0.021	0.144	-0.030	0.008
	(0.092)	(0.024)	(0.145)	(0.033)	(0.049)
Incomplete catch up (HAZ >= -1)	-0.240***	-0.029*	-0.027	0.096***	0.115***
	(0.068)	(0.017)	(0.108)	(0.024)	(0.036)
Late incident stunted	-0.054	-0.020	0.143	0.008	0.059
	(0.087)	(0.022)	(0.127)	(0.031)	(0.046)
Age 7	0.154*	-0.048**	0.355**	-0.049*	-0.010
	(0.082)	(0.021)	(0.156)	(0.029)	(0.043)
Age 8	0.458**	-0.073	0.322	-0.007	-0.094
	(0.195)	(0.050)	(0.294)	(0.069)	(0.103)
Age 9	0.433*	-0.103*	0.401	-0.043	-0.051
	(0.240)	(0.062)	(0.353)	(0.085)	(0.127)
Age 10	-0.022	-0.054	-0.400	0.781***	0.566
	(0.676)	(0.174)	(0.899)	(0.239)	(0.359)
Age 11	0.340	-0.064	-0.802	0.876***	0.743**
	(0.712)	(0.183)	(0.953)	(0.252)	(0.378)
Age 12	0.485	-0.056	-0.776	0.798***	0.723*
	(0.725)	(0.186)	(0.978)	(0.257)	(0.385)
W2 sample	-2.066***	0.014	-0.849	0.770***	0.628*
	(0.658)	(0.169)	(0.867)	(0.233)	(0.349)
W3 sample	-3.745***	-0.060	-1.226	0.871***	0.499
	(0.700)	(0.180)	(0.931)	(0.248)	(0.372)
Age in months at t_1	0.015	0.003	0.025	0.013***	0.016***
	(0.011)	(0.003)	(0.017)	(0.004)	(0.006)
Age in months at t_2	0.030***	-0.001	0.025*	-0.007**	0.003
	(0.009)	(0.002)	(0.014)	(0.003)	(0.005)
African	0.153	0.015	0.076	0.028	-0.042
	(0.097)	(0.025)	(0.163)	(0.035)	(0.051)
Female	0.221***	0.013	-0.125*	-0.038**	-0.106***
	(0.044)	(0.011)	(0.068)	(0.016)	(0.023)
Ln(per capita hh income)	0.091***	0.005	-0.114**	-0.004	-0.020
	(0.033)	(0.008)	(0.051)	(0.012)	(0.018)
Grant received for index child	0.112	0.018	-0.256**	-0.014	0.022
	(0.068)	(0.018)	(0.105)	(0.024)	(0.036)
No. of children < 15y in hh	0.013	-0.001	-0.031*	-0.000	-0.006
	(0.011)	(0.003)	(0.017)	(0.004)	(0.006)
Mom deceased	-0.042	0.001	-0.201	0.027	-0.015
	(0.096)	(0.025)	(0.147)	(0.035)	(0.051)

Mom schooling (years)	0.029***	0.000	-0.011	-0.009***	-0.007
	(0.008)	(0.002)	(0.013)	(0.003)	(0.004)
Mom schooling missing	0.343***	-0.016	-0.167	-0.120***	-0.081
	(0.123)	(0.032)	(0.190)	(0.044)	(0.065)
Urban	-0.009	0.025	0.199**	0.009	0.041
	(0.060)	(0.015)	(0.092)	(0.022)	(0.032)
Eastern Cape	0.103	-0.062*	-0.159	0.031	0.124*
	(0.126)	(0.032)	(0.211)	(0.046)	(0.067)
Northern Cape	0.256**	-0.004	-0.356*	-0.022	-0.029
	(0.123)	(0.032)	(0.208)	(0.044)	(0.065)
Free State	0.222	-0.007	-0.237	0.059	0.013
	(0.143)	(0.037)	(0.235)	(0.051)	(0.076)
KwaZulu-Natal	0.314**	-0.027	-0.410**	0.055	0.008
	(0.122)	(0.031)	(0.204)	(0.044)	(0.065)
Northwest	0.293**	-0.022	-0.193	-0.020	0.038
	(0.144)	(0.037)	(0.231)	(0.052)	(0.076)
Gauteng	0.473***	-0.046	-0.392*	-0.007	-0.022
	(0.136)	(0.035)	(0.218)	(0.049)	(0.072)
Mpumalanga	0.283*	-0.040	-0.285	0.007	0.021
	(0.145)	(0.037)	(0.239)	(0.052)	(0.077)
Limpopo	0.388***	0.012	-0.327	-0.013	-0.011
	(0.139)	(0.036)	(0.226)	(0.050)	(0.074)
Constant	0.519	0.978***	5.423***	-0.658**	-0.829**
	(0.780)	(0.201)	(1.085)	(0.276)	(0.414)
F test: Stunted in t_1 and t_2 = Incomplete catch up	0.22	0.16	0.51	0.52	0.05
Prob>F	0.6424	0.6870	0.4755	0.4704	0.8223
N	834	835	601	824	833

Notes: Standard errors in parentheses. *** p<0.01 ** p<0.05 * p<0.10. Omitted categories are not stunted, Wave 1 sample, age 6, male, rural, Western Cape.

Table 6. Regression results using stricter definition of catch up (HAZ >= -1 in t_2), excluding children aged 6 in Wave 5 (OLS coefficients)

	I	II	III	IV	V
	No. of grades completed	**Enrolled in Gr 1 or higher**	**Age first enrolled**	**Failed in 2016**	**Old for grade**
Stunted in t_1 and t_2`	-0.301***	-0.015	0.089	0.088***	0.142***
	(0.078)	(0.020)	(0.112)	(0.026)	(0.043)
Complete catch up (HAZ < -1)	-0.081	-0.028	0.182	-0.049	0.012
	(0.104)	(0.027)	(0.159)	(0.035)	(0.057)
Incomplete catch up (HAZ >= -1)	-0.234***	-0.035*	-0.022	0.070***	0.127***
	(0.074)	(0.019)	(0.112)	(0.025)	(0.041)
Late incident stunted	-0.058	-0.022	0.144	-0.002	0.074
	(0.096)	(0.025)	(0.133)	(0.033)	(0.053)
F test: Stunted in t_1 and t_2 = Incomplete catch up	0.48	0.65	0.61	0.31	0.08
Prob>F	0.4864	0.4195	0.4357	0.5783	0.7760
N	723	724	561	714	722

Notes: Standard errors in parentheses. *** p<0.01 ** p<0.05 * p<0.10. Omitted category is not stunted. A full set of controls was included as in Table 5.

4. Discussion

This paper explored the association between catch-up growth in height in early childhood and subsequent educational outcomes using the first five waves of NIDS from 2008 to 2017. Catch-up growth is defined as a recovery from stunting between 2 and 4/5 years, and based on this definition, about two-thirds (62%) of the children in the sample who were stunted at 2 years recovered by 4 or 5 years. Children who recovered from stunting in early childhood, however, go on to complete fewer years of schooling when observed again during the primary school years compared to children who were never stunted, and with very similar outcomes to children who remained stunted. In contrast, children who were 'late incident stunted' perform no differently from those who were never stunted. Further, the estimations show that while children in the catch-up group are marginally less likely to be enrolled in school than those who were never stunted, they are much more likely to have failed the grade they had enrolled for in the previous year and to progress more slowly though the schooling system (as are children who remained stunted). These results are consistent with the hypothesis that the first two years of growth are particularly important for subsequent cognitive outcomes, and are in line with the focus in the public health literature on the first 1000-day window of opportunity.

However, there appears to be heterogeneity in outcomes among the catch-up group. Given recent concerns in the literature that recovery from stunting may be too weak a definition of catch up, a stricter definition was also used which required children to have recovered such that their HAZ measurement at 4/5 years fell into what might be considered the 'normal range', i.e. a HAZ greater than -1 (as opposed to the standard -2 cut-off). Based on this cut-off, children were divided into groups loosely labelled 'complete catch up' (HAZ at 4/5 years >=-1) and 'incomplete catch up' (HAZ at 4/5 years <-1). Interestingly, the children in the complete catch up group do no differently from those who were never stunted, while the incomplete catch up group do worse than those who were never stunted, with similar educational outcomes by Wave 5 to those who remained stunted.

This result implies that catch-up growth might mitigate the harmful effects of early growth retardation *only if* the catch up is substantial. Remarkably, very similar results were found by Casale and Desmond (2016) and Casale *et al* (2018), even though they used data from a birth cohort study conducted in Johannesburg from 28 years ago. They found that children who recovered from stunting between the ages of 2 and 5 did worse on cognitive tests at 5 years compared to children who were never stunted, except for the group who caught up such that their HAZ measurement at 5 years had crossed the -1 threshold. They make two important points about this finding which are relevant here. First, while these results may suggest that the extent of catch-up growth matters, it is also possible that this small group of children who catch up to within the normal range by age 5 had different growth trajectories compared to the other children; in other words, they may have been simply 'slow to start' rather than severely malnourished in infancy. Second, even if this more substantial catch-up growth does help to mitigate the harmful effects of early stunting, most stunted children do not recover to this extent. Of children in the NIDS sample who were stunted at 2 years, only 30% have a HAZ greater than -1 at 4/5 years (Casale *et al* 2018 find a very similar percentage in the cohort data). The majority of children do not catch up to this degree and the results suggest that they also do not reach their full cognitive potential.

There are two main limitations to the work. First, the sample size is relatively small given the specific age range analysed and the requirement that children were observed in at least three waves. This is compounded by high rates of missing data on the HAZ variables. Second, although a range of individual- and household-level characteristics were controlled for in the regressions, there may be unobserved heterogeneity that could bias the results. Of particular concern is the possibility that parental preferences for child *quality* might affect both nutritional and educational outcomes (Glewwe and King 2001). In addition, parents might make child-specific complementary (or compensatory) investments depending on the child's cognitive potential, such that children with lower perceived cognitive function receive fewer (greater) nutritional and other parental resources. This is less likely to be a concern, however, when analysing early measures of nutrition, as cognitive potential is harder for parents to gauge at younger ages (Glewwe *et al* 2001). Nonetheless, insofar as these factors are relevant, the results presented in this paper cannot be interpreted as causal.[10]

Given data availability, future work should attempt to explain how much of the effects identified here are due to the child's nutritional status itself and how much might be driven by other confounding factors in the child's caregiving environment. Regardless of what is causing the association, the results indicate that stunted children are vulnerable to poorer educational outcomes, and for most of them, a recovery from stunting is not associated with a mitigation of these effects. More focused attention needs to be directed towards understanding the causes of stunting and preventing its incidence in the first place, as well as investigating the possibility of remediation for those who do fall behind. The prevalence of stunting among 1-3 year olds in South Africa was estimated to be around 27% according to the recent SANHANES data from 2012 (Shisana *et al* 2013); the importance of this as a policy focus therefore cannot be understated.

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