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SOCIAL EPIDEMIOLOGY

Education modifies the relationship between height and cognitive function in a cross-sectional population-based study of older adults in Rural South Africa

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Abstract
We aimed to estimate the relationship between height (a measure of early-life cumulative net nutrition) and later-life cognitive function among older rural South African adults, and whether education modified this relationship. Data were from baseline in-person interviews with 5059 adults $\geq$ 40 years in the population-based "Health and Aging in Africa: A Longitudinal Study of an INDEPTH Community in South Africa" (HAALSI) study in Agincourt sub-district, South Africa, in 2015. Linear regression was used to estimate the relationship between height quintile and latent cognitive function z-score (representing episodic memory, time orientation, and numeracy), with adjustment for life course covariates and a height-by-education interaction. Mean (SD) height was 162.7 (8.9) cm. Nearly half the sample had no formal education (46%; 2307/5059). Mean age- and sex-adjusted cognitive z-scores increased from − 0.68 (95% CI: − 0.76 to − 0.61) in those with no education in the shortest height quintile to 0.62 (95% CI: 0.52–0.71) in those with at least 8 years of education in the tallest height quintile. There was a linear height disparity in cognitive z-scores for those with no formal education (adjusted $\beta = 0.10$; 95% CI: 0.08–0.13 per height quintile), but no height disparity in cognitive z-scores in those with any level of education. Short stature is associated with poor cognitive function and may be a risk factor for cognitive impairment among older adults living in rural South Africa. The height disparity in cognitive function was negated for older adults who had any level of education.

Keywords Cognitive function · Older adults · Education · Height · South Africa

Introduction

By 2050, 70% of dementia cases worldwide are projected to occur in low-and-middle income countries, such as those in sub-Saharan Africa [1]. To date, very little research has focused on the drivers of cognitive health in older populations of this region, either across the full range of cognitive performance or at clinical thresholds for impairment or dementia [2]. In particular, attained adult height, a measure of cumulative net nutrition during growth periods in early-life, is a risk factor that may have a large population-level impact on cognitive health, as stunting (i.e. low height-for-age) remains a common problem affecting approximately 59 million children across the African

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continent in 2016 [3, 4]. A small body of literature has consistently found adult height to be positively associated with cognitive function and inversely associated with dementia risk in diverse study populations [4–15]. These relationships could be the result of two distinct, non-mutually exclusive pathways. First, physical and cognitive development in early-life share common causes through cumulative net nutrition, such that individuals whose physical growth is negatively affected by poor early-life nutritional conditions are likely to also experience poorer cognitive development [16]. Second, taller height may affect cognitive outcomes in later-life by providing socioeconomic and social advantages throughout the life course that lead to cognitive gains and/or protection from aging-related cognitive decline and incident dementia [17–20].

Little is known about factors that might modify any relationship between height and cognitive function, especially in lower-to-middle income countries where the distributions of height, education, and other socioeconomic factors are shifted to the left of those in higher-income contexts. In particular, South Africa operated under Apartheid from 1948 to 1994, a legislated system of forced racial segregation that involved, among many other things, very poor-quality education being available to the black population [21, 22]. Education is one of the strongest influences on peak cognitive ability and is protective against cognitive impairment and dementia in later-life [23–25]. The role of education in promoting cognitive ability may be particularly important in countries like South Africa, where adverse health and nutritional conditions were common for black children and adolescents during Apartheid [21, 22]. The nature of relationship between height, as a measure of early-life cumulative net nutrition, and cognitive function, and whether education might modify this relationship, is unknown among older adults in rural South Africa. The population of this region is rapidly aging, yet has been under-represented in studies of cognitive aging [26].

We hypothesized that there would be a direct positive relationship between attained adult height, as a measure of cumulative net nutrition during early-life growth periods, and cognitive function in later-life that would not be explained by adulthood social advantage factors among older, rural South Africans; and, at the same time, that educational attainment might modify this relationship to the extent that education may have helped nutritionally deprived children to "catch up" on cognitive development. Using data from a population-based study of older adults in rural South Africa, we therefore aimed to: (1) estimate the relationship between attained adult height and cognitive function independently of adulthood social advantage factors, and, (2) examine whether this association was modified by educational attainment.

Methods

Sample

Data were from in-person interviews conducted in the 2015 baseline wave of "Health and Aging in Africa: A Longitudinal Study of an INDEPTH Community in South Africa" (HAALSI), a population-based cohort study of 5059 black men and women aged $\geq$ 40 years (response rate = 86%). Study recruitment and data collection procedures are described in more depth elsewhere [27]. In brief, HAALSI is representative of the Agincourt Health and Socio-Demographic Surveillance System (HDSS), which covers a region of approximately 116,000 people in the Agincourt sub-district, Mpumalanga province, South Africa [27]. Eligible participants were men and women aged $\geq$ 40 years on July 1, 2014 who had resided within the study area for at least 12 months prior to the 2013 Agincourt HDSS Census [27]. Agincourt is part of a "homeland" region of forced racial segregation during Apartheid and is generalizable to other rural areas of South Africa in terms of its demographics and level of economic development [27]. Stunting remains a common problem in this area, as one in five children under age five were stunted in the Agincourt sub-district in 2015 [28].

Measures

Height

Height was measured in centimeters (cm) by trained interviewers during the study interview. Quintiles of height were calculated based on the total sample with complete height data (93%; 4694/5059).

Cognitive function

Cognitive function was assessed using a validated battery of measures assessing orientation in time (ability to state the current day, month, year, and South African president), immediate and delayed recall of ten words read out loud by the interviewer, and numeracy (ability to count from 1 to 20, and complete the final number in the pattern "2, 4, 6…") [25]. One point was given for each correct response, for a total of 26 points. A continuous, z-standardized factor score was derived from these items using confirmatory factor analysis (referred to from here on as "latent cognitive z-score"), the detailed methods for which are described elsewhere [25]. Briefly, the latent variable method improves upon a simple composite summary score (i.e. score out of 26 points), as it allows the individual cognitive measures to vary in their levels of difficulty and contribution to underlying general cognitive performance, it allows for non-linear relationships between the individual cognitive measures and underlying general cognitive performance, and it utilizes only the co-variation between the individual measures to inform the latent cognitive z-score, reducing any measurement error that may be present in any single measure [29].

Education

Education was assessed by self-report in the study interview, and coded as "no education", "some primary (1–7 years)", "some secondary (8–11 years)", or "secondary or more (12 + years)". The latter two categories were collapsed to a "some secondary or more (8 + years)" category, as the number of people with secondary or more education was small, and preliminary analyses showed a plateauing of the relationship between education and latent cognitive z-score after the "some primary" level.

Covariates

We included the following covariates: age (continuous), sex (male; female), country of birth (South Africa; Mozambique or other), father's occupation during childhood (skilled; unskilled; other; don't know), self-rated health during childhood (very bad/bad/moderate vs. good/very good), household wealth and asset quintile, employment status (working; not working; homemaker), marital status (married; unmarried), and number of close social contacts (continuous). Age, sex, country of birth, father's occupation during childhood, and self-rated health during childhood were considered to be potential confounders of the height-cognitive function relationship. Country of birth is an important potential confounder, as nearly one-third of the study population came to South Africa as refugees from the 1977–1992 Mozambique civil war, and have a different health and sociodemographic profile to the South African-born participants [30]. Father's occupation and self-rated health during childhood might be distal partial causes of height [4], although we include them here to account for their potential effects on later-life cognitive function through pathways other than height. Father's occupational skill was assigned based on the International Standard Classification of Occupations 2008, as described in more detail elsewhere [25]. All other covariates were considered to be adulthood social advantage factors that may lie on the causal pathway from height to cognitive function.

Educational attainment is the effect modifier of interest between height and later-life cognitive function, but it may also lie on the causal pathway: we recognize that, once in school, taller children could select into further education on the basis of nutrition conferring better ability to perform well in school and/or of social advantage conferred by their observed height [31, 32]. However, many HAALSI study participants had very little or no formal education, meaning that their schooling was effectively completed before they finished growing and education could not lie on their causal pathway from height to later-life cognitive function. Thus, education was conceptualized primarily as an effect modifier, but we also considered the possibility of it mediating the relationship between height and later-life cognitive function, at least for those individuals who made it into school and then gained further schooling on the basis of their nutrition or height. We recognize that we cannot parse out whether the relationship between height and education is due to height is due to early-life cumulative net nutrition as proxied by height, or due to height per se (i.e. adult social advantage that may be conferred by height). Please see the directed acyclic graph depicted in Supplementary Figure 1.

Missing data

Data on height were complete for 4694/5059 participants (93%). Less than 3% of data were missing on all other variables. Data were analyzed on a complete-case basis, with 4582/5059 participants (91%) included in the analytical sample.

Statistical analysis

First, to assess whether cognitive function and its distribution varied by height, we calculated and visualized the unadjusted means, standard deviations, and distributions of latent cognitive z-scores for each height quintile. Second, we estimated age-and sex-adjusted mean latent cognitive z-scores and associated 95% confidence intervals (CIs) across height quintiles, stratified by level of educational attainment, and conducted an F test of joint equality of the means. Third, we ran a set of five linear regression models predicting the relationship between height quintile and latent cognitive z-score, with iterative adjustment for covariates. Supplementary Figure 1 presents the directed acyclic graph underlying the modeling strategy. Model 1 was unadjusted, model 2 was adjusted for demographic factors (age, sex, and country of birth), model 3 was additionally adjusted for early-life factors (father's occupation and self-rated health during childhood), and model 4 was additionally adjusted for adulthood social advantage factors (current employment status, household wealth and asset quintile, marital status, and number of close social contacts). Model 5 additionally included a main effect for educational attainment along with its multiplicative interaction term with height quintile. To aid with the interpretation of the interaction effect, we estimated and plotted the effects of height quintile on latent cognitive z-score separately for each educational attainment category, holding all covariates constant at their mean values. As a sensitivity analysis, we re-ran the regression models with height (per 10 cm) as the exposure variable. StataSE 15.0 (College Station, TX) was used for all analyses.

Results

Characteristics of the sample are shown in Table 1. Mean age was 61.7 (SD: 13.1) years and just over half of the sample was female (54%; 2714/5059). Mean (SD) height was 162.7 cm (8.9 cm), the range was 99.0–199.2 cm. Nearly half the sample had no formal education (46%; 2307/5059), and only one-fifth had at least some secondary education (20%; 1020/5059). The distribution of height was similar across educational attainment categories, although mean height increased slightly with increasing educational attainment, from 160.9 (SD: 8.6) in those with no education to 166.0 (SD: 8.9) in those with at least some secondary education (Supplementary Table 1). The unadjusted mean latent cognitive z-scores increased across height quintiles, from − 0.40 (SD: 0.99) in the shortest quintile to 0.38 (SD: 0.93) in the tallest height quintile (Fig. 1).

Mean age- and sex-adjusted latent cognitive z-scores increased with increasing educational attainment; the relationship with height quintile varied across levels of educational attainment (test for difference of 15 means: $F(14, 4588) = 83.93$; $p < 0.0001$; test for height by education interaction: $F(8, 4588) = 4.48$; $p < 0.0001$) (Table 2; Fig. 2). In participants with no formal education, there was a linear gradient in latent cognitive z-scores across height quintiles, with mean age- and sex-adjusted z-scores ranging from − 0.68 (95% CI: − 0.75, − 0.61) in the shortest height quintile to − 0.18 (95% CI: − 0.28, − 0.09) in the tallest height quintile; a score disparity of 0.50 SD (Table 2, Fig. 2). In participants with some primary education, mean age- and sex-adjusted latent cognitive z-scores ranged from 0.16 (95% CI: 0.07, 0.26) in the shortest height quintile to 0.31 (95% CI: 0.22, 0.40) in the tallest height quintile, a score disparity of 0.15 SD (Table 2, Fig. 2). There was no height gradient in latent cognitive z-scores in participants with some secondary or more education, with age- and sex-adjusted z-scores ranging from 0.57 (95% CI: 0.42, 0.72) in the shortest height quintile to 0.62 (95% CI: 0.52, 0.71) in the tallest height quintile (Table 2, Fig. 2).

In an unadjusted linear regression model, height was positively associated with latent cognitive z-score (0.18 SD increase per height quintile; 95% CI: 0.16, 0.20; Table 3). After sequential adjustment for age, sex, country of birth, early-life factors, and adulthood factors, the coefficient was attenuated to 0.06 (95% CI: 0.04, 0.09; Table 3). When interacted with education, the estimated effects of height quintile on latent cognitive z-score decreased over educational attainment category, from 0.10 (95% CI: 0.08, 0.13) in those with no formal education to 0.02 (95% CI: − 0.01, 0.05) in those with some primary education and 0.00 (95%

Table 1 Sample characteristics, "Health and Aging in Africa: A Longitudinal Study of an INDEPTH Community in South Africa" (HAALSI)

Characteristic	Total N (%) 5059 (100%)
Height (cm)	
Quintile 1 (99.0–155.0 cm)	954 (20%)
Quintile 2 (155.2–160 cm)	1018 (21%)
Quintile 3 (160.2–165.0 cm)	936 (20%)
Quintile 4 (165.1–170.5 cm)	897 (20%)
Quintile 5 (171.0–199.2 cm)	889 (19%)
Mean (SD)	162.7 (8.9)
Age	
Mean (SD)	61.7 (13.1)
Sex	
Male	2345 (46%)
Female	2714 (54%)
Country of birth	
South Africa	3528 (70%)
Mozambique or other	1526 (30%)
Father's occupation during childhood	
Skilled	2479 (49%)
Unskilled	1446 (29%)
Other	575 (11%)
Don't know	547 (11%)
Self-rated health during childhood	
Very bad/bad/moderate	621 (12%)
Good/very good	4434 (88%)
Educational attainment	
No education	2307 (46%)
Some primary (1–7 years)	1715 (34%)
Some secondary or more (8 + years)	1020 (20%)
Employment status	
Employed (part- or full-time)	805 (16%)
Not working	3719 (74%)
Homemaker	521 (10%)
Marital status	
Married	2575 (51%)
Unmarried	2480 (49%)
Number of close social contacts	
Mean (SD)	3.1 (1.7)

Numbers may not sum to 5059 within individual covariates due to missing data

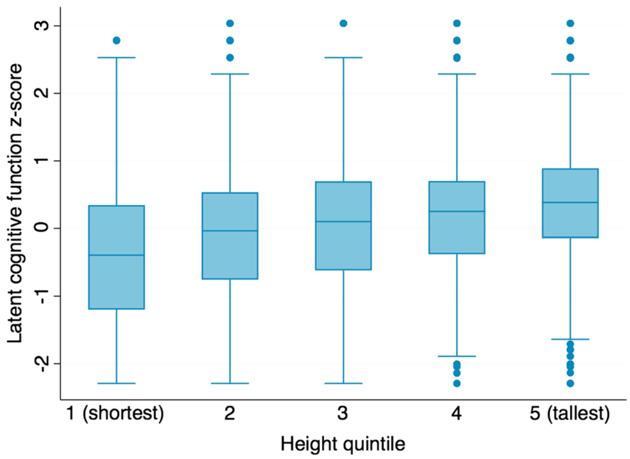

Fig. 1 Box plots of latent cognitive z-scores, by height quintile, HAALSI, South Africa, N = 4582

CI; − 0.04, 0.04) in those with some secondary or more education (Table 3). Figure 3 visualizes these fully-adjusted mean estimated effects of height quintile on cognitive z-score over educational attainment categories, demonstrating a lack of association between height quintile and latent cognitive z-score among study participants who had any level of formal education.

When the regression models were re-run with height coded in 10 cm units, the results were consistent with those shown in Table 3 and Fig. 3 (Supplementary Material).

Discussion

In this population-based study of older adults living in a rural region of South Africa, attained adult height was positively associated with later-life cognitive function. In other words, adults who were taller in later-life tended to have better cognitive performance, on average, than those who were shorter. This association was robust after adjustment for indictors of early-life socioeconomic status and health as well as adulthood social advantage factors that could have conferred by height per se, indicating a direct relationship between height as a measure of cumulative net nutrition during early-life growth periods and cognitive function in later-life. Importantly, there was a height disparity in cognitive function among study participants who had no formal education, but not among those who had at least eight years of education. Given that these study participants were educated under the South African Apartheid system, a time when the quality of education was very low, these findings indicate that there might be a relatively low threshold at which education raises cognitive function, a phenomenon requiring further investigation.

Comparison to other research

These results are consistent with literature from other countries and social contexts demonstrating that attained adult height is associated with cognitive function at various

Table 2 Age- and sex-adjusted mean latent cognitive z-scores, by height quintile, over levels of educational attainment, HAALSI, South Africa, N = 4582

Category	N	Latent cognitive z-score		
		Adj. mean	95% CI	Standard error
No formal education				
Height quintile 1	543	− 0.68	(− 0.76, − 0.61)	0.04
Height quintile 2	474	− 0.48	(− 0.55, − 0.41)	0.04
Height quintile 3	409	− 0.39	(− 0.46, − 0.31)	0.04
Height quintile 4	335	− 0.31	(− 0.39, − 0.22)	0.04
Height quintile 5	272	− 0.18	(− 0.28, − 0.09)	0.05
Some primary education (1–7 years)				
Height quintile 1	275	0.16	(0.07, 0.26)	0.05
Height quintile 2	362	0.25	(0.17, 0.33)	0.04
Height quintile 3	333	0.19	(0.11, 0.28)	0.04
Height quintile 4	326	0.25	(0.16, 0.34)	0.04
Height quintile 5	314	0.31	(0.22, 0.40)	0.05
Some secondary or more (8 + years)				
Height quintile 1	105	0.57	(0.42, 0.72)	0.08
Height quintile 2	163	0.69	(0.57, 0.81)	0.06
Height quintile 3	179	0.65	(0.53, 0.77)	0.06
Height quintile 4	222	0.69	(0.58, 0.80)	0.05
Height quintile 5	293	0.62	(0.52, 0.71)	0.05

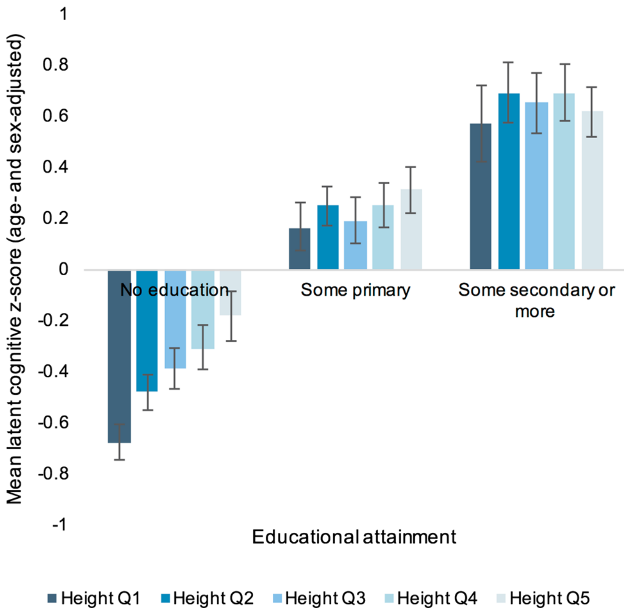

Fig. 2 Mean age- and sex-adjusted latent cognitive z-scores by height quintile, over levels of educational attainment. Error bars represent 95% confidence intervals. HAALSI, South Africa, N = 4582

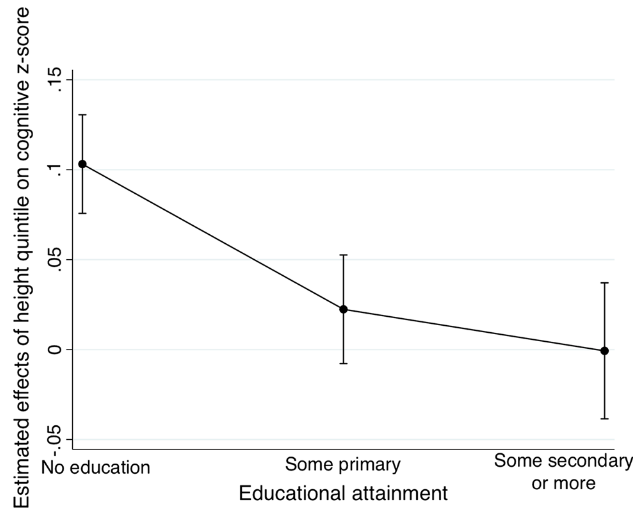

Fig. 3 Adjusted average estimated effects of height quintile on predicted cognitive z-score over educational attainment categories, with 95% confidence intervals, HAALSI, South Africa, N = 4582

points across the life course [4–15]. Our study adds new evidence that this association is present in a rural South African context where poor living conditions were common in early-life due to legislated racial segregation imposed by Apartheid, and that education might modify the relationship between stature and later-life cognitive performance, even in this context where the quality of available education was very poor. During Apartheid in South Africa, black children were often unlikely to reach their genetic potential for height due to their frequently poor living conditions [33]. Still today, one in five children in the Agincourt area and nearly one in four children across South Africa are stunted [28, 34]. Therefore, adult height might be a stronger measure of early-life nutritional conditions in this context than it is in higher-income countries with better living conditions [35], although this postulation is difficult to directly test.

Our study did not support the notion that height is associated with cognitive function in later-life due to height's possible conferral of adulthood social advantages that promote cognitive health. Our effect estimate was negligibly altered after adjustment for employment status, household wealth, marital status, and number of close social contacts. However, other studies should replicate this finding and account for other adulthood variables through which height might be related with cognitive performance, such as the types of employment engaged in

Table 3 Adjusted linear regression models predicting latent cognitive function z-score, HAALSI, South Africa, N = 4582

Model	Adjustments	Per one-quintile height difference	
		β	95% CI
1	Unadjusted	0.18	(0.16, 0.20)
2	Model 1 + age, sex, country of birth	0.08	(0.06, 0.10)
3	Model 2 + early-life factors[a]	0.08	(0.06, 0.10)
4	Model 2 + adulthood factors[b]	0.06	(0.04, 0.09)
5	Model 3 + education + height × education[c]		
	No formal education	0.10	(0.08, 0.13)
	Some primary education (1–7 years)	0.02	(− 0.01, 0.05)
	Some secondary or more (8 + years)	0.00	(− 0.04, 0.04)

[a]Early-life factors are father's occupation during childhood and self-rated health during childhood

[b]Adulthood factors are current employment status, household wealth and asset quintile, marital status, and number of close social contacts

[c]Coefficients from Model 5 are fully-adjusted estimated effects of height quintile over educational categories

or more in-depth variables on social networks and activities. Overall, the results of this study highlight the potential role that education may play in ameliorating the harmful later-life cognitive effects of poor cumulative net nutrition in early-life, although our results should be confirmed in other study populations and country contexts. To the best of our knowledge, no other study has examined whether education might modify the relationship between height and cognitive performance in later-life.

Strengths and limitations

Aging-related shrinkage in physical stature means that the heights measured in this study may not represent fully attained adult height for all study participants, although previous research has demonstrated that any bias due to age-related shrinkage is adequately accounted for by statistical control for age [36]. People who were older, unmarried, uneducated, and who had worse cognitive function scores, worse health, and no social contacts were disproportionately more likely to be missing data on height, and were therefore somewhat under-represented in this sample (see Supplementary Table 2). If those who were missing height data tended to be shorter than those who had height data available, then the association we observed between height and cognitive function would underestimate the true magnitude of the association. This study was cross-sectional and we could not assess cognitive decline or incident cognitive impairment as outcomes. However, temporality is not an issue with respect to our exposure and effect modifier measures, as they are historical measures that would be retrospective even in a longitudinal study of older adults.

Height may be a noisy measure of net cumulative nutrition during early-life growth periods, as there is no way to determine the actual degrees to which it represents net nutrition in addition to genetic factors, disease, or other distal determinants of physical growth. We did not have a measure of educational quality, which, would have been a more precise measure of education's effect on later-life cognitive function than the quantity of education received. The effect modification by education could have been partly driven by unmeasured factors such as parental investment in children, parental knowledge and education, or the selection of high-ability children into schooling. However, the strong economic and political barriers to education in the context of Apartheid South Africa may outweigh these factors. Although we observed an association that was robust to adjustment for several adulthood factors, there are likely to be residual pathways that we have not totally accounted for, such as social support, activities, or quality of contacts [37, 38]. As a consequence, the indirect effects of height on later-life cognitive function through adulthood factors may be greater than indicated by our results. Finally, our results may be biased by residual confounding by early-life socioeconomic or health conditions that were not captured by the measures available in this study. Future work should more deeply investigate the relative roles of height versus other early-life influences on cognitive function in later-life.

The key strength of this study is that it is one of the first population-representative studies of aging in a rural sub-Saharan African setting. We had a large sample size with a comprehensive set of key life course variables that allowed us to assess the robustness of the height-cognitive function relationship in this setting. The distributions of social, economic, and health-related exposures of people living in this context are marked by a long period of Apartheid, where mechanisms of social mobility vastly differed from those observed in studies from higher-income countries [22, 39]. Studies like HAALSI are needed in order to understand the health outcomes faced by older adults in lower-to-middle income settings as global populations age and increasingly face rising burdens of non-communicable diseases, including cognitive declines and impairments [40]. Planned follow-up waves of the HAALSI study will allow for the investigation of risk factors for incident cognitive decline and dementia, in addition to a range of other health outcomes.

Conclusions

Results from this large, population-based study of older, rural South African adults support the postulation that cumulative net nutrition in early-life, as measured by height, is linked to cognitive function in later-life independently of life course factors. Further, we found that the height disparity in cognitive function was negated among older adults who had any level of educational attainment. While educational access has increased over time in South Africa, there remain stark racial- and gender-based inequities in educational access and quality among young South Africans that must be rectified. Given that stunting remains a common problem in South Africa and sub-Saharan Africa more broadly, our findings regarding education may be especially relevant to population health in these regions. Finally, future longitudinal work should document and investigate more deeply the causes of cognitive decline, impairment, and dementia in the older South African population, and aim to develop ways to apply the findings of this and other research to improve the health of the country's older population.

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Compliance with ethical standards

Ethical approval Ethical approval was granted by the University of the Witwatersrand Human Research Ethics Committee (M141159), the Harvard T. H. Chan School of Public Health, Office of Human Research Administration (C13-1608-02), and the Mpumalanga Provincial Research and Ethics Committee. Informed consent was obtained from all individuals included in the study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

1. Prince M, Bryce R, Albanese E, Wimo A, Ribeiro W, Ferri CP. The global prevalence of dementia: a systematic review and meta-analysis. Alzheimers Dement. 2013;9(1):63–75. https://doi.org/10.1016/j.jalz.2012.11.007.
2. Lekoubou A, Echouffo-Techeugui J, Kengne A. Epidemiology of neurodegenerative diseases in sub-Saharan Africa: a systematic review. BMC Public Health. 2014;14:653. https://doi.org/10.1186/1471-2458-14-653.
3. UNICEF, WHO, World Bank Group. Levels and Trends in Child Malnutrition. http://www.who.int/nutgrowthdb/jme_brochoure2017.pdf. Published May 2017. Accessed 30 Jan 2017.
4. Perkins JM, Subramanian SV, Smith GD, Özaltin E. Adult height, nutrition, and population health. Nutr Rev. 2016;74(3):149–65. https://doi.org/10.1093/nutrit/nuv105.
5. Stewart R, Hardy R, Richards M. Associations between skeletal growth in childhood and cognitive function in mid-life in a 53-year prospective birth cohort study. PLoS ONE. 2015;10(4):1–10. https://doi.org/10.1371/journal.pone.0124163.
6. Abbott RD, White LR, Ross GW, et al. Height as a marker of childhood development and late-life cognitive function: the Honolulu–Asia aging study. Pediatrics. 1998;102(3):602–9.
7. Melrose RJ, Brewster P, Marquine MJ, et al. Early life development in a multiethnic sample and the relation to late life cognition. J Gerontol Ser B Psychol Sci Soc Sci. 2015;70(4):519–31. https://doi.org/10.1093/geronb/gbt126.
8. Yount KM, Hoddinott J, Stein AD, DiGirolamo AM. Individual capital and cognitive ageing in Guatemala. Popul Stud. 2009;63(3):295–306. https://doi.org/10.1080/00324720903165464.
9. Laitala VS, Hjelmborg J, Koskenvuo M, et al. Shorter Adult Stature Increases the Impact of Risk Factors for Cognitive Impairment: a Comparison of Two Nordic Twin Cohorts. Twin Res Hum Genet. 2011;14(6):544–52. https://doi.org/10.1375/twin.14.6.544.
10. Beeri MS, Davidson M, Silverman JM, Noy S, Schmeidler J, Goldbourt U. Relationship between body height and dementia. Am J Geriatr Psychiatry. 2011;13(2):116–23. https://doi.org/10.1176/appi.ajgp.13.2.116.
11. Maurer J. Height, education and later-life cognition in Latin America and the Caribbean. Econ Hum Biol. 2010;8(2):168–76. https://doi.org/10.1016/j.ehb.2010.05.013.
12. Zhang Z, Gu D, Hayward MD. Childhood nutritional deprivation and cognitive impairment among older Chinese people. Soc Sci Med. 2010;71(5):941–9. https://doi.org/10.1016/j.socscimed.2010.05.013.
13. Case A, Paxson C. Height, health, and cognitive function at older ages. Am Econ Rev. 2008;98(2):463–7. https://doi.org/10.1257/aer.98.2.463.
14. Akachi Y, Canning D. The height of women in Sub-Saharan Africa: the role of health, nutrition, and income in childhood. Ann Hum Biol. 2007;34(4):397–410. https://doi.org/10.1080/03014460701452868.
15. Huang TL, Carlson MC, Fitzpatrick AL, Kuller LH, Fried LP, Zandi PP. Knee height and arm span: a reflection of early life environment and risk of dementia. Neurology. 2008;70:1818–26. https://doi.org/10.1212/01.wnl.0000311444.20490.98.
16. Grantham-McGregor S, Cheung YB, Cueto S, Glewwe P, Richter L, Strupp B. Developmental potential in the first 5 years for children in developing countries. Lancet. 2007;369(9555):60–70. https://doi.org/10.1016/S0140-6736(07)60032-4.
17. LaFave D, Thomas D. Height and cognition at work: labor market productivity in a low income setting. Econ Hum Biol. 2017;25:52–64. https://doi.org/10.1016/j.ehb.2016.10.008.
18. Deaton A, Arora R. Life at the top: the benefits of height. Econ Hum Biol. 2009;7(2):133–6. https://doi.org/10.1016/j.ehb.2009.06.001.
19. Batty GD, Shipley MJ, Gunnell D, et al. Height, wealth, and health: an overview with new data from three longitudinal studies. Econ Hum Biol. 2009;7(2):137–52. https://doi.org/10.1016/j.ehb.2009.06.004.
20. Case A, Paxson C. Stature and status: height, ability, and labor market outcomes. Cambridge: National Bureau of Economic Research; 2006. NBER Working Paper 12466.
21. Christie P, Collins C. Bantu education: Apartheid ideology and labour reproduction. In: Kallaway P, editor. Apartheid and Education. Braamfontein: Raven Press; 1984. p. 160–83.
22. United Nations. Apartheid in South Africa: summary of the report of the special committee on the policies of apartheid of the Government of South Africa. New York: United Nations; 1963.
23. Nguyen TT, Tchetgen EJT, Kawachi I, et al. Instrumental variable approaches to identifying the causal effect of educational attainment on dementia risk. Ann Epidemiol. 2015;26(1):71–6. https://doi.org/10.1016/j.annepidem.2015.10.006.
24. Clouston SAP, Kuh D, Herd P, Elliott J, Richards M, Hofer SM. Benefits of educational attainment on adult fluid cognition: international evidence from three birth cohorts. Int J Epidemiol. 2012;41(6):1729–36. https://doi.org/10.1093/ije/dys148.
25. Kobayashi LC, Glymour MM, Kahn K, et al. Childhood deprivation and later-life cognitive function in a population-based study of older rural South Africans. Soc Sci Med. 2017;10:25.
26. Kabudula CW, Houle B, Collinson MA, et al. Progression of the epidemiological transition in a rural South African setting: findings from population surveillance in Agincourt, 1993–2013. BMC Public Health. 2017;17(1):424. https://doi.org/10.1186/s12889-017-4312-x.
27. Kahn K, Collinson MA, Xavier Gómez-olivé F, et al. Profile: agincourt health and socio-demographic surveillance system. Int J Epidemiol. 2012;41(4):988–1001. https://doi.org/10.1093/ije/dys115.
28. Kimani-Murage EW, Kahn K, Pettifor JM, et al. The prevalence of stunting, overweight and obesity, and metabolic disease risk in rural South African children. BMC Public Health. 2010;10:158. https://doi.org/10.1186/1471-2458-10-158.
29. Muthén L, Muthén B. Examples: confirmatory factor analysis and structural equation modeling. In: Muthén L, Muthén B, editors. MPlus user's guide. 6th ed. Los Angeles: Muthén & Muthén; 2017. p. 55–112.

30. Sartorius K, Sartorius B, Tollman S, Schatz E, Kirsten J, Collinson M. Rural poverty dynamics and refugee communities in South Africa: a spatial-temporal model. Popul Space Place. 2013;19(1):103–23. https://doi.org/10.1002/psp.697.
31. Cinnirella F, Piopiunik M, Winter J. Why does height matter for educational attainment? Evidence from German children. Econ Hum Biol. 2011;9(4):407–18. https://doi.org/10.1016/j.ehb.2011.04.006.
32. Magnusson PKE, Rasmussen F, Gyllensten UB. Height at age 18 is a strong predictor of attained education later in life: cohort study of over 950 000 Swedish men. Int J Epidemiol. 2006;35(3):658–63. https://doi.org/10.1093/ije/dyl011.
33. Said-Mohamed R, Micklesfield LK, Pettifor JM, Norris SA. Has the prevalence of stunting in South African children changed in 40 years? A systematic review. BMC Public Health. 2015;15(1):534. https://doi.org/10.1186/s12889-015-1844-9.
34. World Health Organization. Child stunting: prevalence of stunting in children under 5. World Health Statistics Data Visualization Dashboard. http://apps.who.int/gho/data/node.sdg.2-2-viz-1?lang=en. Accessed November 30, 2017.
35. Gale C. Commentary: height and intelligence. Int J Epidemiol. 2005;34(3):678–9. https://doi.org/10.1093/ije/dyi064.
36. Fernihough A, McGovern ME. Physical stature decline and the health status of the elderly population in England. Econ Hum Biol. 2015;16:30–44. https://doi.org/10.1002/ana.22528.Toll-like.
37. Glei DA, Landau DA, Goldman N, et al. Participating in social activities helps preserve cognitive function: an analysis of a longitudinal, population-based study of the elderly. Int J Epidemiol. 2005;34(4):864–71. https://doi.org/10.1093/ije/dyi049.
38. Bassuk SS, Glass TA, Berkman LF. Social disengagement and incident cognitive decline in community-dwelling elderly persons. Ann Intern Med. 1999;131(3):165–73.
39. United Nations Centre Against Apartheid. The effects of apartheid on the status of women in South Africa. Black Sch. 1978;10(1):11–20. https://doi.org/10.1080/00064246.1978.11412667.
40. Tollman SM, Norris SA, Berkman LF. Commentary: the value of life course epidemiology in low-and middle-income countries: an ageing perspective. Int J Epidemiol. 2016;45(4):997–9. https://doi.org/10.1093/ije/dyw109.