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Long-term household material socioeconomic resources and cognitive health in a population-based cohort of older adults in rural northeast South Africa, 2001–2015

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A B S T R A C T

Material resources owned by households that affect daily living conditions may be salient for cognitive health during aging, especially in low-income settings, but there is scarce evidence on this topic. We investigated relationships between long-term trends in household material resources and cognitive function among older adults in a population-representative study in rural South Africa. Data were from baseline interviews with 4580 adults aged ≥40 in "Health and Ageing in Africa: A Longitudinal Study of an INDEPTH Community in South Africa" (HAALSI) in 2014/2015 linked to retrospective records on their household material resources from the Agincourt Health and Socio-Demographic Surveillance System (HDSS) from 2001 to 2013. Household material resources were assessed biennially in the Agincourt HDSS using a five-point index that captured dwelling materials, water and sanitation, sources of power, livestock, and technological amenities. Cognitive function was assessed in HAALSI and analyzed as a z-standardized latent variable capturing time orientation, episodic memory, and numeracy. We evaluated the relationships between quintiles of each of the mean resource index score, volatility in resource index score, and change in resource index score and subsequent cognitive function, overall and by resource type. Higher mean household resources were positively associated with cognitive function ($\beta_{adj} = 0.237$ standard deviation [SD] units for the highest vs. lowest quintile of mean resource index score; 95% CI: 0.163–0.312; p-trend<0.0001), as were larger improvements over time in household resources ($\beta_{adj} = 0.122$ SD units for the highest vs. lowest quintile of change in resources; 95% CI: 0.040–0.205; p-trend = 0.001). Results were robust to sensitivity analyses assessing heterogeneity by age and restricting to those with formal education. The findings were largely driven by technological amenities including refrigerators, stoves, telephones, televisions, and vehicles. These amenities may support cognitive function through improving nutrition and providing opportunities for cognitive stimulation through transportation and social contact outside of the home.

1. Background

Evidence from a variety of global settings indicates that markers of socioeconomic status across the life course are associated with dementia risk in later-life (Cadar et al., 2018; Clouston et al., 2015; Glymour et al., 2012; Kaplan et al., 2001; Karp et al., 2004; Kobayashi et al., 2017; Lang et al., 2008; Marden et al., 2017; Singh-Manoux et al., 2005). Socioeconomic status is thought to be related to dementia risk through impacting financial resources, social class, access to health care, opportunities for social engagement, and lifestyle behaviors that are dementia risk factors (Benton, 2010; Fratiglioni et al., 2004; Hall et al., 2009; Livingston et al., 2020). Most evidence on socioeconomic status and dementia risk is from populations in high-income countries and focuses on individual-level financial measures such as income or wealth that are taken at single points in time (Cadar et al., 2018; Kaplan et al., 2001; Karp et al., 2004; Lang et al., 2008; Singh-Manoux et al., 2005). Little is known about the role of dynamic, longitudinal trends in socioeconomic status in relation to dementia risk, especially in populations

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living in low- and middle-income countries (LMICs), where the socioeconomic welfare of individuals and their households may be volatile over time. Given that over 75% of the global burden of dementia is projected to occur in LMICs by 2050 (Patterson, 2018), this evidence gap limits the understanding of dementia etiology in LMIC settings as well as possible effective strategies to reduce or delay its onset. Actionable research on the role of household socioeconomic dynamics in relation to dementia risk in LMIC settings is thus urgently needed.

Few studies have investigated longitudinal trends in socioeconomic status markers in relation to later-life dementia risk. In the United States (US), sustained poverty and a high degree of income volatility over a 20-year period in mid-life have been associated with lower subsequent cognitive performance (Grasset et al., 2019; Zeki Al Hazzouri et al., 2017). In China, a nationally representative study found that a longer duration of poverty after age 65 was associated with a lower subsequent level of cognitive function, but a slower rate of cognitive decline (Yu et al., 2021). The slower rate of cognitive decline observed in this study is consistent with the compensation hypothesis of cognitive reserve as applied to longitudinal cognitive decline, and not mutually exclusive of poverty being associated with lower cognitive performance at baseline (Yu et al., 2021). A handful of other studies from the US, England, and Eastern Europe have examined retrospectively reported socioeconomic measures from time points in early- and mid-life, consistently finding that higher socioeconomic status is positively associated with later-life cognitive aging outcomes (Al Hazzouri et al., 2011; Horvat et al., 2014; Marden et al., 2017; Singh-Manoux et al., 2005). To represent life course socioeconomic status, these studies primarily used measures of parental education or occupation, financial circumstances in childhood, educational attainment, and adulthood occupation or income.

No study to-date on socioeconomic conditions and cognitive aging has focused on the material resources held by households that impact daily living conditions, such as sources of power, sources of water and sanitation, housing materials, or technological amenities for entertainment, transportation, and communication. Key dementia risk factors including obesity, high blood pressure, depression, air pollution, physical inactivity, and social disengagement are influenced by the daily living conditions imposed by these types of material resources held by households (Livingston et al., 2020; Mukadam et al., 2019). These risk factors are thought to influence dementia risk primarily through their impacts on cognitive reserve, which is theorized as an individual's degree of adaptability to maintain cognitive function in day-to-day tasks despite neuropathological decline or insults (Stern et al., 2020). Household material resources may promote cognitive reserve and function through improving nutrition, reducing air pollution in the home, and providing opportunities for cognitive stimulation through leisure activities, social contact, and communication outside the home (Livingston et al., 2020; Stern et al., 2020).

We aimed to investigate the relationship between long-term trends in household material resources (dwelling materials, water and sanitation, sources of power for cooking and lighting, livestock, and technological amenities) over a 13-year period and subsequent cognitive function in a population-representative study of adults aged ≥40 years in the rural Agincourt sub-district, Mpumalanga province, South Africa. We examined three types of long-term trends in household material resources, overall and by resource type: 1) mean level of resources across the 13-year exposure period, 2) volatility in ownership of resources across the 13-year exposure period, and 3) overall change over time in ownership of resources across the 13-year exposure period. We hypothesized that: 1) greater mean levels of resources, 2) less volatility in resource ownership, and 3) greater positive changes over time in resource ownership across the 13-year exposure period would be associated with higher subsequent cognitive function scores. We included a series of sensitivity analyses to evaluate the potential impact of missing data, heterogeneity in the studied associations by age, and the potential for reverse causality, using level of education as a proxy indicator of early-life cognitive function.

2. Methods

2.1. Study setting

The Agincourt sub-district in Mpumalanga province, South Africa, is a semi-arid rural region with a population of ~116,000 people living across 31 villages in an area of ~450 km^2 (Kahn et al., 2012). The Agincourt sub-district is part of a former "homeland" region of racial segregation in South Africa, where Black South Africans were forcibly settled during apartheid (1948–1994) based on their racial and ethnic identity (United Nations, 1963, p. 47). Since the end of apartheid, social and economic conditions in Agincourt have improved, but there remain gaps in the availability of basic services such as piped water and tarred roads (Kahn et al., 2012). Approximately one-third of the Agincourt population are former refugees who immigrated to the region during the civil war and its aftermath in neighboring Mozambique from 1977 to 1992, and their descendants (Sartorius et al., 2013).

2.2. Study design and participants

Data were from the baseline wave of a population-representative longitudinal cohort study, "Health and Ageing in Africa: A Longitudinal Study of an INDEPTH Community in South Africa" (HAALSI), linked to retrospective regional census records from the Agincourt Health and Socio-Demographic Surveillance System (Agincourt HDSS). Data on household material resources were collected biennially in the Agincourt HDSS from 2001 through 2013, and data on cognitive function and covariates were collected in the HAALSI baseline interviews in 2014 and 2015.

The Agincourt HDSS was established in 1992 to support evaluations of decentralized health systems development during South Africa's post-apartheid restructuring of the country's health care system (Kahn et al., 2012). The Agincourt HDSS involves an annual regional census with complete population coverage of the Agincourt sub-district, with in-person household interviews with trained local fieldworkers in the local Shangaan (Xitsonga) language. The Agincourt HDSS originally included 21 villages selected for their rural living conditions, limited access to public sector services, underperforming primary care clinics, and communities of Mozambican refugees displaced by the civil war (Kahn et al., 2012). In response to an expanding trials and evaluation portfolio, the census region expanded to 26 villages in 2007, and another five villages were added between 2010 and 2012. Regular census modules capture information on employment, household assets, healthcare utilization, and receipt of government grants (Kahn et al., 2012).

HAALSI is a longitudinal cohort study that investigates health and aging, and it is representative of the Agincourt HDSS population aged ≥40 years as its sampling frame (Gómez-Olivé et al., 2018). Its design and measures are harmonized with those of the United States Health and Retirement Study (HRS) and its other International Partner Studies of aging, to build capacity for understanding cross-national differences in health and well-being during aging. A total of 5059 men and women aged ≥40 years on July 1, 2014, who had lived in the region for at least 12 months prior to the 2013 Agincourt HDSS census consented to participate (86% response rate). Data were collected through in-home interviews conducted by trained local fieldworkers in the local Shangaan (Xitsonga) language from November 2014 through November 2015. Of the 5059 HAALSI participants, 132 (2.6%) were missing cognitive outcome data, as they either had a proxy interview (n = 116) or declined to complete the cognitive assessment (n = 32). A further 36 (<1.0%) had no household resource data recorded in the Agincourt HDSS, 281 (5.7%) had household resources recorded at fewer than three time points, which prevented us from estimating their longitudinal exposure variables, and 30 (<1%) were missing covariate data, for a final analytical sample of 4580.

Ethical approval was granted by the University of the Witwatersrand

Human Research Ethics Committee (M110138, M180585, M960720 and M081145 for the Agincourt HDSS; M141159 for HAALSI; M200556 for the present analysis), the Harvard T. H. Chan School of Public Health Office of Human Research Administration (C-13-1608-02 for HAALSI), and the Mpumalanga Provincial Research and Ethics Committee (approval numbers N/A). The University of Michigan Health Sciences and Behavioral Sciences Review Board (HUM00181917) and the Indiana University Human Research Protection Program (2002584956) provided ethical approval for the present analysis. Informed consent was obtained at every Agincourt HDSS surveillance update visit from the head of the household or another eligible adult in the household, and from all HAALSI study participants.

2.3. Measures

2.3.1. Mid-to-later life household material resources (2001–2013, agincourt HDSS)

Material resources of the household were assessed every two years from 2001 through 2013 in the Agincourt AHDSS as using an absolute index that captured the ownership or presence of resources in the home. The index captured a variety of indicators belonging to five categories of household resources: 1) construction materials of the main dwelling structure, 2) sources of power for lighting and cooking, 3) source of water and type of sanitation facilities, and 4) ownership of livestock, and 5) technological amenities, such as a refrigerator, television, telephone, and vehicles (Kahn et al., 2012). Indicators within each category were assigned weights, with higher values corresponding to greater socioeconomic status (Supplementary Table 1). For example, for the indicator "type of toilet facility" in the water and sanitation category, a lack of toilet facility in home was assigned a weight of 1 and a flush toilet in the home was assigned a weight of 4. The observed values for each indicator were divided by the highest possible value for that indicator, to obtain normalized values that ranged from 0 to 1 (Kabudula et al., 2017a). The normalized indicators within each household resource category were summed and normalized again using the same method to obtain values ranging from 0 to 1 for each category (Kabudula et al., 2017a). The category-specific values were summed at each time point, to obtain a total household material resource score with a possible range from 0 to 5 at each time point (Kabudula et al., 2017a). This method of calculating an absolute household assets index based on socioeconomic resources has been used extensively by Agincourt HDSS researchers and is modelled on the Demographic and Health Surveys (DHS) index created for use in low- and middle-income settings (Kabudula et al., 2017a, 2017b; Riumallo-Herl et al., 2019; Xavier Gómez-Olivé et al., 2010).

2.3.2. Later-life cognitive function (2014–2015, HAALSI)

Cognitive function was assessed in the HAALSI interview using validated measures harmonized with those used in the HRS and its International Partner Studies (Kobayashi et al., 2021; Ofstedal et al., 2005). These were: orientation in time (ability to state the present year, month, date, and name of the current South African president; one point for each), immediate word recall (the number of words correctly recalled, out of ten, from a list read aloud by the interviewer; ten points); delayed word recall (the number of words correctly recalled from the original list of ten words after a 1 min delay during which the respondent was asked unrelated questions; ten points), forward count (the ability to count correctly from 1 to 20; one point), and number skip pattern (the ability to complete the final digit of the number skip pattern beginning with 2, 4, 6, administered if the participant was able to correctly count from 1 to 20; one point). We used confirmatory factor analysis to generate a latent cognitive z-score based on all measures, standardized to a mean of 0 and standard deviation of 1 (Kobayashi et al., 2017). The latent cognitive z-score represents the covariation between individual cognitive measures, which reduces measurement error and improves precision relative to a simple summary composite score (Gross et al., 2015).

2.3.3. Covariates

Potential confounders were assessed in the HAALSI interview: age (continuous), sex (male; female), country of birth (South Africa; Mozambique or other), having parents in a union when the respondent was born (yes; no), having a parent who died before the respondent was aged 18 (yes; no), father's occupation during childhood (skill levels one through four according to the International Standard Classification of Occupations [ISCO] 2008; other; don't know), self-rated health in childhood (very good; good; moderate; bad; very bad), highest level of education (no formal education; some primary [1–7 years]; some secondary [8–11 years]; secondary or more [12+ years]), self-reported literacy (cannot read and/or write; can read and write), and smoking history (ever smoker; never smoker). Occupational status in the year 2000, immediately prior to when household material resources were measured, was assessed from the Agincourt HDSS (skill levels one through four according to the ISCO 2008; not working; missing). A "missing" indicator for this variable was incorporated, as most respondents living in villages that were added to the Agincourt HDSS region after 2001 did not provide these data. The most common occupations within each of the four ISCO 2008 categories were as follows: Level 1: construction, farm, and domestic manual labor; Level 2: mining and service sector work; Level 3: traditional healers and small business assistants; Level 4: a range of professional or managerial work, such as owning a small business or being a teacher or healthcare worker.

2.4. Statistical analysis

We estimated *mean household resources* for each person as the within-person mean of the total household resource score measured from 2001 to 2013, encompassing all five categories of resources (range: 0–5). We estimated *volatility in household resources* for each person as the within-person standard deviation (SD) of the percent change in the total household resource score year-to-year from 2001 to 2013. We calculated the percent change year-to-year for each person in the sample as $100*(Y_{t+1}\text{-}Y_t)/0.5(Y_{t+1}+Y_t)$, where Y = total household resources, as per Dynan et al. (Dynan et al., 2012). If a participant was missing next-year data on the total resource score, we used data from the next available year. We estimated *change over time in household resources* by fitting within-person simple linear regression models using all available observations on total household resource score for each person from 2001 to 2013 and extracting the slope estimates. We categorized each of these three longitudinal exposure variables into quintiles to facilitate interpretation in subsequent modelling steps.

We used multivariable linear regression models to estimate the associations between each quintile measure of household resources from 2001 to 2013 and cognitive function in 2014/2015. All models followed this general specification, shown below in Equation (1):

$$Cog_{2014/15} = \beta_0 + \beta_1 Resource_q2_{2001-2013} + \beta_2 Resource_q3_{2000-2013} + \beta_3 Resource_q4_{2000-2013} + \beta_4 Resource_q5_{2000-2013} + \beta Covs + \alpha + \varepsilon_i \quad [1]$$

Where $Cog_{2014/15}$ is the latent cognitive function z-score at the HAALSI baseline in 2014/15, β_0 is the model intercept (i.e., the mean cognitive z-score for an individual in the lowest quintile of the household resource score exposure variable and in the reference categories of all covariates), $\beta_1 Resource_q2_{2000-2013}$ through $\beta_4 Resource_q5_{2000-2013}$ represent the estimates for the mean difference in cognitive z-score for each of quintiles 2 through 5 of the household material resource score (for each of the three operationalizations of the score), relative to the lowest quintile (quintile 1). The term *Covs* represents the vector of covariates, described above, which were adjusted for in all models, and α is a fixed effect for the HAALSI study interviewer, as previous work has shown that cognitive function scores differ systematically by interviewer identity (Harling et al., 2020). We ran models using both the total household resources score, incorporating all five categories of resources, and for each resource category separately, to evaluate whether different types of

resources had differential associations with cognitive function. All models were adjusted for the covariates listed above, while the models for volatility and change over time in household resources were additionally adjusted for the initial value of the household resources score. We clustered the standard errors for all models at the household level. All statistical analyses were conducted using StataSE 15.1 (College Station, Texas).

We conducted four sensitivity analyses using the total household resource score to assess the robustness of our findings. First, we re-ran the analysis restricting the sample to participants with complete observations on household resources at all time points, to explore whether the inclusion of those with incomplete observations altered the findings. Second, we re-ran the analysis using multiple imputation for missing values of household material resources and covariates (He, 2010). Under the assumption of missing at random (MAR), we used IVEware: Imputation and Variation Estimation Software Version 0.3 (available from: https://www.src.isr.umich.edu/software/) to impute missing observations using the sequential regression multivariate imputation approach. We imputed ten datasets, and used the technique presented by He et al. to compute the point estimate and associated confidence intervals across the datasets (He, 2010). Third, we re-ran our analysis stratified by age at the time of the cognitive assessment (≤60 versus >60) to examine for heterogeneity by age. Fourth, to evaluate the potential for reverse causality whereby those with better cognitive health at the start of the exposure period may have had more household material resources, we re-ran our analysis restricted to individuals with any level of formal education as a proxy of early-life cognitive health, as education is a strong determinant of later-life cognitive health (Livingston et al., 2020).

Role of the funding source

The study sponsors had no role in the study design; in the collection, analysis, or interpretation of data; in the writing of the report; or in the decision to submit the paper for publication.

2.5. Data sharing

The de-identified HAALSI data are publicly available at: https://haalsi.org/data. The de-identified Agincourt HDSS data may be accessed through data use agreement at: https://www.agincourt.co.za/?page_id=1883.

3. Results

Characteristics of the sample are shown in Table 1. Individuals who were excluded from the analytic sample (n = 479; 9.5%) were more likely to have been born in Mozambique and to have lower education and literacy than those who were included, reflecting the demographics of the villages added to the Agincourt HDSS after 2001 (Supplementary Table 2). Individuals living in villages that were added to Agincourt HDSS after 2001 had a higher rate of missing data than those included in the HDSS from 2001 or earlier. Mean cognitive function did not differ between included and excluded individuals (−0.004 SD units vs. 0.05 SD units; $p = 0.328$). The population distribution of household material resources improved and shifted to the right over time, while variability in the distribution of household resources decreased over time (Fig. 1). This finding largely reflects the general improvement in the socioeconomic circumstances of the Agincourt sub-district over the study period. The quintile cut-off values for the three household resource exposure variables indicated a relatively narrow range in mean household resources and relatively little volatility in resources in this population over the study period (Table 2). When broken down by type of household resource, the quintile cut-offs similarly indicated relatively little volatility and an overall improvement over time for all types of household resources (Supplementary Table 3). The two types of resources displaying the greatest volatility were technological amenities and livestock, and livestock was the amenity that showed the greatest amount of decline over time in this sample (Supplementary Table 3). Characteristics of the sample according to quintiles of each household resource variable are shown in Supplementary Tables 4-6.

Table 1
Characteristics of the sample, Agincourt sub-district, Mpumalanga, South Africa, n = 4580.

Characteristic	n (%)
Age at the time of cognitive assessment (years)	
Mean (SD)	61.9 (12.9)
Sex	
Male	2106 (46%)
Female	2474 (54%)
Country of birth	
South Africa	3241 (71%)
Mozambique or other	1339 (29%)
Parents in a union when born	
Yes	4257 (93%)
No	323 (7%)
Parent died before respondent was age 18	
No	3996 (87%)
Yes	584 (13%)
Father's main job during childhood	
Skill level 1 (lowest skill)	1308 (29%)
Skill level 2	1997 (44%)
Skill level 3	140 (3%)
Skill level 4 (highest skill)	128 (3%)
Other	523 (11%)
Don't know	484 (10%)
Self-rated health in childhood	
Very good	3199 (70%)
Good	823 (18%)
Moderate	260 (6%)
Bad	149 (3%)
Very bad	149 (3%)
Education	
No formal education	2059 (45%)
Some primary (1–7 years)	1605 (35%)
Some secondary (8–11 years)	524 (11%)
Secondary or more (≥12 years)	392 (9%)
Self-reported literacy	
Can read and write	2710 (59%)
Cannot read and/or write	1870 (41%)
Occupation in the year 2000	
Skill level 1 (lowest skill)	895 (19%)
Skill level 2	1248 (27%)
Skill level 3 or 4 (highest skill)	324 (7%)
Not working	808 (18%)
Missing	1305 (28%)
Smoking history	
Never smoker	3619 (79%)
Current or former smoker	982 (21%)

Note: All participant characteristics were assessed in the HAALSI study in 2014/2015 (the time of cognitive assessment), except for occupation was assessed in the year 2000.

Mean total household resources from 2001 to 2013 was strongly positively associated with higher cognitive function scores in 2014/2015 in a linear, dose-response fashion (p-value for linear trend <0.0001; Table 3). Respondents in the highest quintile of the mean household resource score had, on average, cognitive scores that were 0.237 SD units higher (95% CI: 0.163, 0.312) than those in the lowest quintile of mean household resources over the period from 2001 to 2013 (Table 3). This association appeared to be largely driven by technological amenities, which were associated with cognitive function scores in a dose-response fashion (p-value for linear trend <0.0001; Table 4), with cognitive scores being 0.197 SD units higher (95% CI: 0·099, 0.160) among those in the highest versus lowest quintile of the technological amenities score (Table 4). Mean dwelling materials over the period from 2001 to 2013 were also associated with cognitive function in 2014/2105 (p-value for linear trend 0.038; Table 4).

Volatility in total household resources from 2001 to 2013 was not

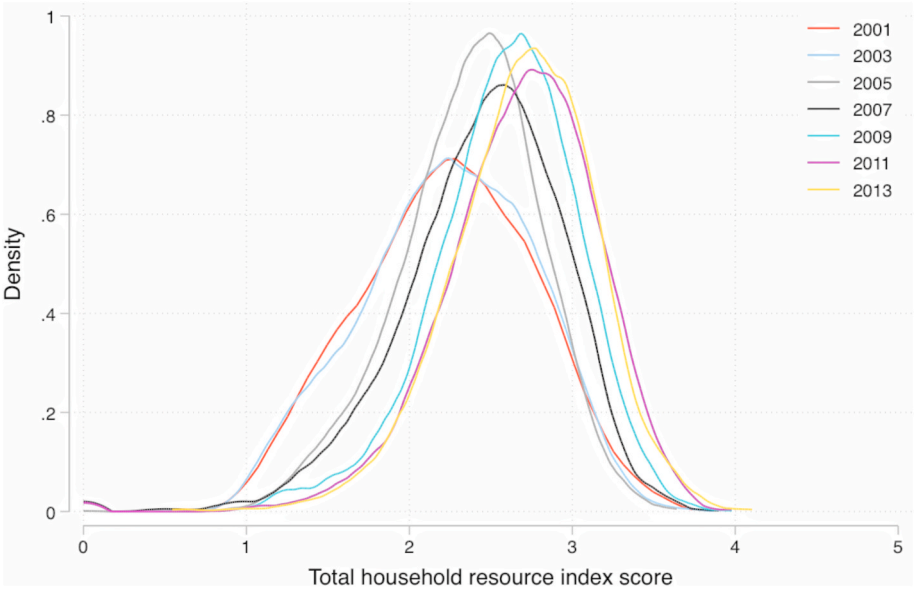


Fig. 1. Kernel density plot of total household resource score (possible range: 0-5) from 2001 through 2013, Agincourt sub-district, Mpumalanga, South Africa, n=4,580.

Table 2
Quintile cut-offs for the total household resource exposure variables, Agincourt sub-district, Mpumalanga, South Africa, n = 4580.

Quintile	Total household resources, 2001–2013		
	Mean level of resources	Volatility in resources	Change over time in resources
1 (lowest)	1.093 to 2.145	0.327 to 7.341	−0.194 to 0.015
2	2.146 to 2.404	7.342 to 10.089	0.016 to 0.037
3	2.405 to 2.603	10.090 to 12.976	0.038 to 0.056
4	2.604 to 2.832	12.977 to 16.969	0.057 to 0.084
5 (highest)	2.833 to 3.638	16.970 to 48.667	0.085 to 0.360

Note: The total household resources variable ranged from 0 to 5. Mean level of resources was calculated as the within-person mean of all observations over the period 2001–2013. Volatility in resources was calculated as the standard deviation of the within-person year-to-year percent change in resources over the period 2001–2013. Change over time in resources was calculated as the within-person change over time (slope) in resources over the period 2001–2013.

associated with cognitive function in 2014/2015 in this sample, with estimates that were weak in magnitude and relatively precisely estimated (Table 3). However, greater volatility in technological amenities over this period was negatively associated with cognitive function (*p*-value for linear trend <0.0001; Table 4), with cognitive scores being 0.172 SD units lower (95% CI: −0.172, −0.083) among those in the highest versus lowest quintile of volatility in technological amenities (Table 4). Volatilities in other types of household resources were not associated with subsequent cognitive function, again with precise estimates that were close to the null in magnitude (Table 4).

Positive changes over time in total household resources from 2001 2013 were positively associated with cognitive function in 2014/2015, with a linear, dose-response relationship (*p*-value for linear trend was 0.001; Table 3). However, the estimates for individual quintiles of change were weak and not statistically significant, except for the highest quintile of change in resources (0.122 SD units; 95% CI: 0.040, 0.205; Table 3). As with mean household resources, this association appeared to be driven by positive changes over time in technological amenities, which were positively associated with cognitive function (0.092 SD units; 95% CI: 0.007, 0.178 for highest vs. lowest quintile of change; *p*-value for linear trend 0.013; Table 4).

The results were consistent with the main analysis when we restricted models to respondents who had complete data on household resources at all time points (Supplementary Table 7), and when we performed multiple imputation to fill in missing values of household resources and model covariates (Supplementary Table 8). These sensitivity analyses indicate that incomplete and missing observations to not appear to bias our results. Results did not meaningfully differ by age group (Supplementary Table 9), indicating that the associations between household material resources and cognitive function do not vary across life course periods in mid-to-later life. The results also did not meaningfully differ when the analysis was restricted to individuals with formal education (Supplementary Table 10). Finally, we ran a *post-hoc* sensitivity analysis re-running our main models excluding technological amenities from the total household resource score, to examine whether this category of resources was driving the findings for the main associations. We observed precise null results for the mean household resource score in relation to cognitive function when technological amenities were excluded from the mean household resource score, providing support for technological amenities as the type of resource driving these findings (Supplementary Table 11).

4. Discussion

In this large, population-representative study of adults aged ≥40 years in rural northeast South Africa, greater household ownership of material resources and large improvements over time in material resources over a 13-year period were strongly associated with improved subsequent cognitive health for individuals living in households. These findings were largely driven by technological amenities in the home, such as refrigerators, stoves, phones, televisions, and vehicles. Notably, we observed that households in this region of South Africa improved in their socioeconomic circumstances over time from 2001 to 2013, with little volatility in resources and rare overall losses in resources during

Table 3
Multivariable-adjusted associations between total household resources from 2001 to 2013 and cognitive function in 2014/2015, Agincourt sub-district, Mpumalanga, South Africa, n = 4580.

Quintile of total household resources	Cognitive function z-score (SD units)	
	Coef.	95% CI
Mean total household resources, 2001–2013		
1 (lowest)	Ref	–
2	0.058	(-0.012, 0.128)
3	0.162	(0.092, 0.231)
4	0.191	(0.120, 0.263)
5 (highest)	0.237	(0.163, 0.312)
p-value for linear trend		<0.0001
Volatility in total household resources, 2001–2013		
1 (lowest)	Ref	–
2	−0.025	(-0.094, 0.044)
3	−0.043	(-0.110, 0.024)
4	−0.091	(-0.163, −0.020)
5 (highest)	−0.021	(-0.098, 0.057)
p-value for linear trend		0.193
Change over time in total household resources, 2001–2013		
1 (lowest)	Ref	–
2	−0.016	(-0.085, 0.054)
3	−0.023	(-0.097, 0.052)
4	0.059	(-0.016, 0.134)
5 (highest)	0.122	(0.040, 0.205)
p-value for linear trend		0.001

Note: Standard errors in models are clustered at the household level. The total household resources variable ranged from 0 to 5. Mean level of resources was calculated as the within-person mean of all observations over the study period. Volatility in resources was calculated as the standard deviation of the within-person year-to-year percent change in resources over the study period. Change over time in resources was calculated as the person-specific slope in resources over the study period. Models are adjusted for age at the cognitive assessment, sex, country of birth, whether parents were in a union when the respondent was born, having a parent who died before the respondent was 18, father's occupational skill level during childhood, self-rated health in childhood, highest level of education, self-reported literacy, occupational status in the year 2000, smoking history, and HAALSI interviewer identity. Models for volatility and change over time in household resources were additionally adjusted for the baseline household resource score.

the period. This observation reflects the broadly improving socioeconomic and political circumstances of the region following the end of apartheid in the early 1990s (Kahn et al., 2012). The present results indicate that the improvement of technological amenities for food preparation, transportation, and communication outside of the household may be beneficial for the cognitive health of older adults. As populations in low-income regions around the world are rapidly aging and expected to carry much of the global dementia burden in the coming decades, this study underscores the importance of ensuring the material socioeconomic welfare of households with older adults in these settings.

5. Comparison to existing literature and potential mechanisms

Our results are consistent with a body of cross-sectional and longitudinal evidence across high-, middle-, and low-income settings finding that indicators of socioeconomic status are associated with cognitive aging outcomes (Al Hazzouri et al., 2011; Cadar et al., 2018; Clouston et al., 2015; Glymour et al., 2008, 2012; Glymour & Manly, 2008; Grasset et al., 2019; Kaplan et al., 2001; Karp et al., 2004; Kobayashi et al., 2017; Lang et al., 2008; Marden et al., 2017; Richards & Sacker, 2010; Singh-Manoux et al., 2005; Yu et al., 2021; Zeki Al Hazzouri et al., 2017). Most of this literature has examined socioeconomic indicators at a single point in time, even when there is longitudinal follow-up for incident cognitive outcomes. Our results are consistent with a US study, which found that sustained poverty over a 20-year period among adults aged 18–30 years at baseline was associated with lower subsequent scores on tests of verbal memory, processing speed, and executive function (Zeki Al Hazzouri et al., 2017), and a study of adults aged ≥65 in China, which also found that a longer duration of poverty was associated with lower cognitive function (Yu et al., 2021). However, no studies that we are aware of have examined household material resources as a socioeconomic exposure in relation to cognitive aging outcomes.

The null associations that we observed between all quintiles of volatility and the middle quintiles of change over time in household resources were unexpected. This finding may be because households in the Agincourt region generally improved in their socioeconomic welfare over the study period, with few overall losses and little negative volatility in material resources (Kabudula et al., 2017a). Future studies in other global settings where older populations have experienced different trajectories of socioeconomic circumstances should be valuable in further elucidating the relationships between household material resources and subsequent cognitive health. The technological amenities that we studied may have influenced cognitive function through providing opportunities for better quality nutrition (refrigerators and stoves for food storage and preparation), and opportunities for direct cognitive stimulation from access to media and entertainment (televisions and satellites), communication outside of the household (telephones), and transportation outside of the household (vehicles). Use of these resources may serve to build cognitive reserve, allowing individuals to adapt and maintain cognitive functional ability during aging despite aging-related neuropathological decline or insults (Stern et al., 2020). Indeed, the activities described above that are supported by access to the technological resources under study here have all been associated with improved cognitive function and reduced risk of dementia (Fratiglioni et al., 2004; Hall et al., 2009; James et al., 2011; Jennings et al., 2020; Livingston et al., 2020; Sommerland et al., 2020). The other types of household resources under study, while important for general health and quality of life, may not have had the same cognitively stimulating effects as the technological amenities under study. Mediation analyses are needed to evaluate the pathways through which access to material resources in the household may influence cognitive health in later-life. Future research should conduct these analyses, as well as replicate and confirm the present findings in other populations and settings.

6. Limitations

Participants had to maintain survival over the exposure period from 2001 to 2013 to be included in the analysis. If those who died over this period had fewer household material resources and worse cognitive health, then the observed associations may underestimate the true magnitudes of associations. This type of selective survival bias is always an unmeasurable possibility in studies of aging, as it involves population mortality that occurs prior to when individuals are sampled to take part in baseline study interviews (e.g., the HAALSI interview in 2014/2015 in the case of this study). Reverse causality is possible, whereby individuals with higher cognitive function at the start of the study period may have been better able to accumulate or hold onto household material resources over time. Our sensitivity analyses restricting to those with formal education as a proxy of earlier-life cognitive health showed similar results to the main analysis. We did not measure cognitive domains such as executive function, processing speed, or language. These domains warrant investigation in other studies. The cognitive function outcome was measured at a single point in time in this study. Future longitudinal follow-up of the HAALSI cohort will allow us to examine cognitive change over time and incidence of cognitive impairment and dementia in relationship to household material resources and other key socioeconomic measures.

7. Strengths

The Agincourt HDSS and HAALSI cohort capture a large, population-

Table 4
Multivariable-adjusted associations between household resources from 2001 to 2013, by type, and cognitive function in 2014/15, Agincourt sub-district, Mpumalanga, South Africa, n = 4580.

Quintile of household resources, by type	Cognitive function z-score (SD units)					
	Mean resources		Volatility in resources		Change over time in resources	
	Coef.	95% CI	Coef.	95% CI	Coef.	95% CI
Dwelling materials, 2001–2013						
1 (lowest)	Ref	–	Ref	–	Ref	–
2	0.042	(-0.030, 0.116)	−0.015	(-0.084, 0.053)	0.028	(-0.045, 0.101)
3	0.046	(-0.034, 0.125)	−0.063	(-0.136, 0.010)	0.058	(-0.013, 0.129)
4	0.070	(-0.019, 0.159)	−0.027	(-0.104, 0.051)	0.071	(-0.003, 0.145)
5 (highest)	0.108	(0.013, 0.203)	−0.010	(-0.088, 0.068)	0.059	(-0.022, 0.140)
p-value for linear trend		0.038		0.847		0.093
Water and sanitation facilities, 2001–2013						
1 (lowest)	Ref	–	Ref	–	Ref	–
2	0.049	(-0.026, 0.123)	−0.035	(-0.104, 0.035)	−0.001	(-0.070, 0.067)
3	0.021	(-0.057, 0.099)	−0.007	(-0.078, 0.063)	−0.011	(-0.084, 0.062)
4	0.019	(-0.059, 0.097)	−0.053	(-0.124, 0.018)	−0.025	(-0.104, 0.054)
5 (highest)	−0.002	(-0.082, 0.079)	−0.075	(-0.149, 0.000)	−0.035	(-0.121, 0.051)
p-value for linear trend		0.653		0.060		0.291
Power sources, 2001–2013						
1 (lowest)	Ref	–	Ref	–	Ref	–
2	0.057	(-0.093, 0.207)	−0.016	(-0.080, 0.047)	0.019	(-0.055, 0.094)
3	−0.045	(-0.011, 0.020)	−0.050	(-0.109, 0.009)	0.000	(-0.087, 0.087)
4	−0.024	(-0.103, 0.055)	0.053	(-0.022, 0.127)	0.131	(0.020, 0.242)
5 (highest)	0.073	(-0.014, 0.160)	–	–	–	–
p-value for linear trend		0.182		0.799		0.126
Technological amenities, 2001–2013						
1 (lowest)	Ref	–	Ref	–	Ref	–
2	0.144	(0.070, 0.218)	−0.077	(-0.147, −0.007)	0.019	(-0.055, 0.093)
3	0.142	(0.064, 0.220)	−0.110	(-0.184, −0.037)	0.066	(-0.010, 0.141)
4	0.134	(0.048, 0.221)	−0.127	(-0.207, −0.048)	0.081	(0.002, 0.161)
5 (highest)	0.197	(0.099, 0.294)	−0.172	(-0.260, −0.083)	0.092	(0.007, 0.178)
p-value for linear trend		<0.0001		<0.0001		0.013
Livestock, 2001–2013						
1 (lowest)	Ref	–	Ref	–	Ref	–
2	−0.043	(-0.113, 0.027)	0.009	(-0.062, 0.081)	0.022	(-0.055, 0.099)
3	−0.017	(-0.089, 0.055)	−0.040	(-0.110, 0.030)	0.059	(-0.025, 0.142)
4	−0.005	(-0.079, 0.069)	−0.017	(-0.089, 0.055)	0.026	(-0.051, 0.102)
5 (highest)	0.006	(0.083, 0.071)	−0.051	(-0.121, 0.019)	0.043	(-0.034, 0.121)
p-value for linear trend		0.912		0.090		0.404

Note: Standard errors in models are clustered at the household level. The mean household resources variables are normalized indicators ranging from 0 to 1. Mean level of resources was calculated as the within-person mean of all observations over the study period. Models are adjusted for age at the cognitive assessment, sex, country of birth, whether parents were in a union when the respondent was born, having a parent who died before the respondent was 18, father's occupational skill level during childhood, self-rated health in childhood, highest level of education, self-reported literacy, occupational status in the year 2000, smoking history, and HAALSI interviewer identity. The five types of household resources were mutually adjusted for in the same model. There are four quartiles for volatility and change over time in power sources because low volatility and change over time in this resource (29% had no volatility and 32% had no change over time in power sources) prevented the calculation of quintiles.

representative sample. We were able to examine fine-grained aspects of levels, volatility, and changes in household material resources over a long exposure period. Few previous studies of socioeconomic conditions and cognitive aging outcomes have used dynamic, longitudinal exposure measures such as these. These longitudinal data were captured using a widely used absolute socioeconomic resource index adapted from the DHS, improving the utility of our findings for comparison against other studies. Our cognitive outcome data were adapted from the validated assessment used in the US HRS (Kobayashi et al., 2021). Losses of abilities in the cognitive function domains captured in this assessment, namely the ability to orient oneself in place and time and episodic memory function, are hallmark early signs of dementia (Ofstedal et al., 2005). Our results were robust to a series of sensitivity analyses to explore implications of missing data, age heterogeneity, and reverse causality, and we adjusted for a range of key confounders including sociodemographic factors, health conditions, and early-life socioeconomic conditions.

8. Conclusions and future directions

In this study of adults aged ≥40 years in a rural region of South Africa, we observed that greater household material resources as well as large increases over time in household resources over a 13-year period were positively and strongly associated with better subsequent cognitive function. These findings were largely driven by technological amenities in the household, suggesting that improving access to these amenities, such as food storage and preparation appliances, telephones, televisions, and vehicles may be beneficial for the cognitive health of older adults in rural, sub-Saharan African settings. These findings are consistent with cognitive reserve theory (Stern et al., 2020) and require investigation in other global settings and populations.

Ethical approval

Ethical approval was granted by the University of the Witwatersrand Human Research Ethics Committee (M110138, M180585, M960720 and M081145 for the Agincourt HDSS; M141159 for HAALSI; M200556 for the present analysis), the Harvard T. H. Chan School of Public Health Office of Human Research Administration (C-13-1608-02 for HAALSI), and the Mpumalanga Provincial Research and Ethics Committee (approval numbers N/A). The University of Michigan Health Sciences and Behavioral Sciences Review Board (HUM00181917) and the Indiana University Human Research Protection Program (2002584956) provided ethical approval for the present analysis. Informed consent was

obtained at every Agincourt HDSS surveillance update visit from the head of the household or another eligible adult in the household, and from all HAALSI study participants.

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CRediT authorship contribution statement

Lindsay C. Kobayashi: Conceptualization, Funding acquisition, Investigation, Methodology, Data curation, Formal analysis, Visualization, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Chodziwadziwa Whiteson Kabudula:** Investigation, Methodology, Resources, Data curation, Writing – review & editing. **Mohammed U. Kabeto:** Methodology, Data curation, Formal analysis, Writing – review & editing. **Xuexin Yu:** Methodology, Data curation, Formal analysis, Writing – review & editing. **Stephen M. Tollman:** Conceptualization, Investigation, Funding acquisition, Resources, Writing – review & editing. **Kathleen Kahn:** Conceptualization, Investigation, Funding acquisition, Resources, Writing – review & editing. **Lisa F. Berkman:** Conceptualization, Investigation, Funding acquisition, Resources, Writing – review & editing. **Molly S. Rosenberg:** Conceptualization, Investigation, Funding acquisition, Project administration, Resources, Writing – review & editing.

Declaration of competing interest

None.

Data availability

The de-identified HAALSI data are publicly available at: https://haalsi.org/data. The de-identified Agincourt HDSS data may be accessed through data use agreement at: https://www.agincourt.co.za/

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2022.101263.

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