Neuroepidemiology

Original Paper

Neuroepidemiology 2025;59:110–119
DOI: 10.1159/000539578

Received: February 5, 2024
Accepted: May 11, 2024
Published online: June 10, 2024

Mid-Life Household Food Insecurity and Subsequent Memory Function and Rate of Decline in Rural South Africa, 2004–2022

Xuexin Yu[a] Audra Gill[a] Rishika Chakraborty[b]
Chodziwadziwa W. Kabudula[c] Ryan G. Wagner[c] Darina T. Bassil[d]
Meagan T. Farrell[d] Stephen M. Tollman[c] Kathleen Kahn[c]
Molly S. Rosenberg[c, e] Lindsay C. Kobayashi[a, c]

[a]Center for Social Epidemiology and Population Health, Department of Epidemiology, University of Michigan School of Public Health, Ann Arbor, MI, USA; [b]Department of Environmental and Occupational Health, Indiana University School of Public Health-Bloomington, Bloomington, IN, USA; [c]MRC/Wits Rural Public Health and Health Transitions Research Unit (Agincourt), School of Public Health, Faculty of Health Sciences, University of Witwatersrand, Johannesburg, South Africa; [d]Harvard Center for Population and Development Studies, Harvard T.H. Chan School of Public Health, Cambridge, MA, USA; [e]Department of Epidemiology and Biostatistics, Indiana University School of Public Health-Bloomington, Bloomington, IN, USA

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Keywords
Food insecurity · Memory function · Memory decline · South Africa

Abstract
Introduction: We aimed to investigate mid-life food insecurity over time in relation to subsequent memory function and rate of decline in Agincourt, rural South Africa. ***Methods:*** Data from the longitudinal Agincourt Health and Socio-Demographic Surveillance System (Agincourt HDSS) were linked to the population-representative Health and Aging in Africa: A Longitudinal Study of an INDEPTH Community in South Africa (HAALSI). Food insecurity (yes vs. no) and food insecurity intensity (never/rarely/sometimes vs. often/very often) in the past month were assessed every 3 years from 2004 to 2013 in Agincourt HDSS. Cumulative exposure to each food insecurity measure was operationalized as 0, 1, and ≥2 time points. Episodic memory was assessed from 2014/15 to 2021/22 in HAALSI. Mixed-effects linear regression models were fitted to investigate the associations of each food insecurity measure with memory function and rate of decline over time. ***Results:*** A total of 3,186 participants (mean age [SD] in 2004: 53 [12.87]; range: 30–96) were included and 1,173 (36%) participants experienced food insecurity in 2004, while this figure decreased to 490 (15%) in 2007, 489 (15%) in 2010, and 150 (5%) in 2013. Experiencing food insecurity at one time point (vs. never) from 2004 to 2013 was associated with lower baseline memory function ($\beta = -0.095$; 95% CI: −0.159 to −0.032) in 2014/15 but not rate of memory decline. Higher intensity of food insecurity at ≥2 time points (vs. never) was associated with lower baseline memory function ($\beta = -0.154$, 95% CI: −0.338 to 0.028), although the estimate was imprecise. Other frequencies of food insecurity and food insecurity intensity were not associated with memory function or decline in the fully adjusted models. ***Conclusion:*** In this setting, mid-life food insecurity may be a risk factor for lower later-life memory function, but not decline.

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Correspondence to:
Lindsay C. Kobayashi, lkob@umich.edu

Background

Food insecurity is a substantial global public health issue, with approximately 29% of the global population experiencing moderate or severe food insecurity in 2020 [1]. The experience of food insecurity has been associated with poor later-life cognitive health outcomes across diverse socioeconomic settings [2–8]. Potential mechanisms have been proposed to support the biological plausibility of this association. Individuals experiencing food insecurity often have limited access to diverse high-quality diets, which may result in malnutrition [9], an important risk factor for high blood pressure and diabetes in mid- to later life [10, 11]. The sustained experience of food insecurity over the life course may also increase psychological stress [12, 13], which may repeatedly trigger inflammatory and metabolic responses [14], leading to elevated risk of multiple chronic diseases, including cardiovascular diseases and depression [15–17]. All these pathways have been implicated in the etiology of Alzheimer's disease and related dementias (ADRD) [18, 19].

Although food insecurity is a time-varying exposure, most prior epidemiological studies have measured it at a single point in time [3, 4, 6, 8, 20]. Studies that have incorporated repeated measures of food insecurity have been primarily from high-income countries (HICs) [2, 5, 7]. For instance, recent evidence from the USA indicates that food insecurity experienced over a span of 16 years in mid- to later life may contribute to a faster rate of memory decline during aging [5]. There is scarce longitudinal evidence on food insecurity exposure and its outcomes from low- and middle-income countries (LMICs), where most of the world's food insecure populations reside [1, 21]. South Africa is one of these countries, with a national prevalence of food insecurity consistently exceeding 20% over the past decade [22]. Moreover, there exist differences across HICs and LMICs, such as those in population dietary patterns and structural policies related to public health care and social welfare [23, 24]. These cross-national variations may modify the impacts of food insecurity on subsequent health outcomes, which remains understudied.

We aimed to investigate the association between household food insecurity from 2004 to 2013 and subsequent memory function and rate of decline from 2014 to 2022 among individuals aged ≥30 years in 2004 in rural South Africa. We hypothesized that food insecurity over the 9-year exposure period would be associated with lower memory function and a faster rate of decline over the subsequent 7-year follow-up period.

Methods

Study Population, Data Sources, and Analytic Sample

Study Population

The study site, Agincourt, is an under-resourced rural region of Mpumalanga province, South Africa, near the Mozambique border [25]. Agincourt covers ~450 km^2 with ~120,000 individuals living in 31 villages. During South African Apartheid (1948–1994), Agincourt was designated as a "*homeland*," where black South Africans belonging to the Tsonga ethnic group were forcibly resettled based on their ethnic identity [26, 27]. This population group in Agincourt largely speaks Shangaan, an unofficial language spoken by the Tsonga people in northeast South Africa [28]. Additionally, this population group received poor quality education during Apartheid due to policies that limited the quality, content, funding, and accessibility of schooling, all of which were aimed to ensure that black South Africans remained engaged in low-skilled manual labor [29, 30]. The legislated racial segregation that involved limited access to education resulted in long-lasting high unemployment rates and slow economic growth post-Apartheid [26, 27].

Data Sources

Data used in this study were from the Agincourt Health and Socio-Demographic Surveillance System (Agincourt HDSS) from 2004 to 2013 linked to a population-representative longitudinal cohort study that used the Agincourt HDSS as its sampling frame, "Health and Aging in Africa: A Longitudinal Study of an INDEPTH Community in South Africa" (HAALSI) from 2014/15 to 2021/22 [25, 31]. The Agincourt HDSS is a regional census-based platform with nearly 100% population coverage in the Agincourt area since 1992 [25]. In the Agincourt HDSS, trained local field staff conduct in-person household interviews in the local Shangaan language to collect annual data on vital events (births, deaths, and migrations) and socioeconomic characteristics (e.g., education, employment, household assets, and food insecurity) in less frequent, but regular, intervals [25].

HAALSI is a population-representative longitudinal cohort study of males and females aged ≥40 years residing in Agincourt [31]. The HAALSI cohort is embedded in the Agincourt HDSS with a sampling frame of 12,875 individuals identified using the 2013 Agincourt HDSS [31]. A total of 6,281 individuals were randomly selected from this sampling frame to participate in HAALSI, with 5,059 individuals enrolled in 2014/15 (86% response rate) [31]. In-person interviews with trained local field staff were conducted in the local Shangaan language to collect comprehensive data on a range of topics including demographics, employment, social conditions, cognitive and physical health, and health-care utilization.

Analytic Sample

We excluded individuals (1) whose data failed to be linked between two cohorts (n = 4, 0.07%), (2) who were added to the Agincourt HDSS after the year 2004 due to an expansion of its geographic surveillance region and thus with no data collected in 2004 (n = 1,133, 22.39%), (3) who did not have complete data on food insecurity from 2004 to 2013 (n = 671, 13.25%), and (4) who had missing data on memory scores at the HAALSI baseline in 2014/15 (n = 65, 1.28%), leading to a sample size of

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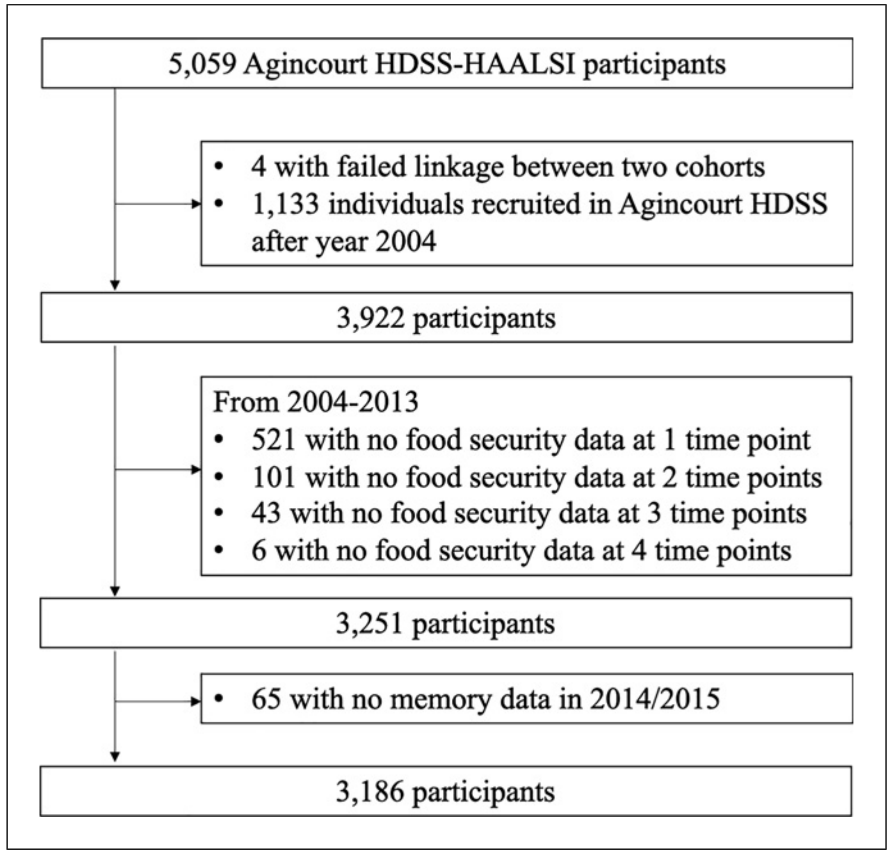

Fig. 1. Study flow diagram, Agincourt HDSS-HAALSI, Agincourt, Mpumalanga, South Africa, 2004–2022.

3,186 individuals, who contributed 7,889 memory outcome observations in HAALSI from 2014/15 to 2021/22 (3,186 observations in HAALSI Wave 1; 2,523 observations in HAALSI Wave 2; 2,180 observations in HAALSI Wave 3, Fig. 1). Characteristics of individuals who were included and excluded from this analysis are shown in online supplementary Table 1 (for all online suppl. material, see https://doi.org/10.1159/000539578).

Measures

Exposure 1: Household Food Insecurity from 2004 to 2013

Household food insecurity was measured in the Agincourt HDSS in 2004, 2007, 2010, and 2013. Participants were asked the question “Has your household not had enough food to eat in the last month?” (response options: yes; no). We defined food insecurity from 2004 to 2013 according to the frequency of “yes” responses: never (n = 1,545/3,186; 48%), at one time point (n = 1,097/3,186; 34%), and at ≥ two time points (n = 544/3,186; 17%). We combined those with food insecurity at two time points (n = 438/3,186; 14%), three time points (n = 95/3,186; 3%), and four time points (n = 11/3,186; 0.4%) to maintain an adequate sample size across each exposure category.

Exposure 2: Household Food Insecurity Intensity from 2004 to 2013

The intensity of household food insecurity was measured using the question “How often did your household not have enough food to eat in the last month?” (response options: very often; often; sometimes; rarely; never). We defined food insecurity intensity according to the frequency of “often” or “very often” responses from 2004 to 2013 as never (n = 2,492/3,169; 79%), one time point (n = 598/3,169; 19%), and ≥ two time points (n = 79/3,169; 3%). A total of 17 records had missing data on the intensity of food insecurity, leading to a reduced analytic sample for this exposure (N = 3,169).

Outcome: Latent Memory Z-Scores from 2014 to 2022

Episodic memory function was measured using immediate and delayed word recall tests (scores ranging from 0 to 10 for each test) at each of three waves of HAALSI data collection in 2014/2015, 2019/2020, and 2021/2022 [31]. Due to differential administration in immediate word recall tests in HAALSI (one test in HAALSI Wave 1 and three tests in HAALSI Waves 2–3), we used confirmatory factor analysis to create longitudinally harmonized factor scores representing latent episodic memory scores at each wave [32, 33]. The latent memory scores were standardized at each time point using the mean and standard deviation of the baseline distribution, which had a mean of 0 and a standard deviation of 1. Higher scores indicate higher memory function, with coefficients for change in memory scores over time (slopes) referring to change relative to the baseline distribution. Details of the creation of latent memory scores can be accessed elsewhere [33].

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Covariates in 2004

We controlled for demographic characteristics, childhood socioeconomic status, and adulthood socioeconomic status at the exposure period baseline in 2004 as potential confounders of the association between food insecurity and memory outcomes [2, 5]. Time-constant covariates (childhood indicators, country of birth, self-reported literacy, and education) were measured in the HAALSI 2014/2015, although they were used to reflect baseline characteristics in 2004.

Demographic characteristics were baseline age (continuous), sex (male; female), and country of birth (South Africa; Mozambique; or other). Childhood socioeconomic covariates included having parents in a union when the respondent was born (yes; no), having a parent who died before the respondent was aged 18 years (yes; no), father's occupational skill level during childhood, according to the International Standard Classification of Occupations (ISCO) (lower-skill occupation [levels 1–2]; higher-skill occupation [levels 3–4]; other; unknown) [34], and self-rated health in childhood (very good; good; moderate; bad; very bad). Five indicators of adulthood socioeconomic status at baseline were included: marital status (married or partnered; single; separated or divorced; widowed), the 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), household asset-based wealth index (in quintiles) measured in 2003 [35], and occupational skill level measured in 2004, also according to the ISCO (non-employment; lower-skill occupation [levels 1–2]; higher-skill occupation [levels 3–4]).

Statistical Analysis

We examined the distribution of baseline characteristics overall and by the food insecurity exposures. We used multiple imputations with chained equations to produce 5 datasets with imputed values for all covariates that had missing data [36]. We retained all variables from our analytic models including the food insecurity exposures, latent memory z-scores measured in 2014/2015, and baseline covariates in the imputation models to make the missing at-random assumption more plausible [36].

We fitted mixed-effects linear regression models with person-specific random slopes and random intercepts to investigate the associations of each of mid-life household food insecurity and food insecurity intensity from 2004 to 2013 with subsequent memory function and decline. We fitted three sequentially adjusted model sets for each of the associations: Model 1 adjusted for demographic characteristics only, Model 2 adjusted for demographic characteristics and childhood socioeconomic status, and Model 3 adjusted for all covariates described above. Years of follow-up were calculated as the calendar time since HAALSI Wave 1 (range: 0–7.25 years). We included the interaction between years of follow-up and each mid-life household food insecurity and food insecurity intensity in the models to examine their associations with the rate of memory decline (slope) from 2014 to 2022. We included a binary indicator for HAALSI Wave 1 (vs. Waves 2/3) to account for practice effects due to repeated memory tests over time [37]. We tested for potential confounding of the slope estimates for food insecurity by including the interaction terms between years of follow-up and each of the covariates. None of these interactions altered the slope estimates for food insecurity and were thus removed from the models.

As in the context of the study region in South Africa, traditional gender norms are common and women may be more likely than men to sacrifice their own quantity and quality of food for their children [38], we tested for effect modification by sex by including a three-way interaction between each of the food insecurity exposures, years of follow-up, and sex. Results for the effect modification by sex were not statistically significant (online suppl. Table 2). Therefore, the statistical interactions were removed from the main models.

We conducted two sensitivity analyses. First, we repeated our analyses using imputed data for food insecurity among those with missingness at one time point (n = 522), two time points (n = 99), and three time points (n = 40) to retain a sample size of 3,831. As recommended by a prior study of approaches to impute incomplete longitudinal data in life course epidemiology [39], we used predictive mean imputation to impute missing observations of food insecurity at each time point and then constructed the longitudinal food insecurity exposure variables based on imputed data. Second, we incorporated inverse probability weights of censoring and mortality to account for potential selective attribution bias during the HAALSI follow-up [40].

Results

This study included 3,186 participants (mean age [SD]: 53 [12.87], Table 1). A total of 1,173 (36%) participants experienced food insecurity in 2004, while this figure decreased to 490 (15%) in 2007, 489 (15%) in 2010, and 150 (5%) in 2013 (online suppl. Table 3), indicating a dramatic improvement of food accessibility over time in Agincourt. The prevalence of higher intensity of food insecurity also declined from 12% (394/3,169) in 2004, 5% (174/3,169) in 2007, 5% (162/3,169) in 2010, to 1% (33/3,169) in 2013 in this study sample (online suppl. Table 3). Table 1 shows the distributions of baseline covariates and memory scores according to food insecurity exposure from 2004 to 2013. Online supplementary Table 4 provides the distribution of baseline covariates by food insecurity intensity from 2004 to 2013.

Table 2 provides estimates and 95% confidence intervals (CI) for the association of food insecurity from 2004 to 2013 with subsequent memory function and rate of decline. Compared to those who never reported food insecurity from 2004 to 2013, individuals who experienced food insecurity at one time point (β = −0.152, 95% CI: −0.219 to −0.085, $p < 0.001$) and ≥ two time points (β = −0.164, 95% CI: −0.249 to −0.079, $p < 0.001$) had lower memory function at the HAALSI baseline in 2014/15 (Model 1), indicating a dose-response relationship. However, the estimates were attenuated after adjusting for childhood and adulthood socioeconomic status (β = −0.095, 95% CI: −0.159 to −0.032, p = 0.004, one time point vs. never; β = −0.062, 95% CI: −0.143 to 0.019, p = 0.131, ≥ two time

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points vs. never; Model 3). The interaction between food insecurity and years of follow-up suggested that food insecurity was not associated with a subsequent rate of memory decline in this context (β = 0.011, 95% CI: −0.003 to 0.025 for food insecurity at one time point vs. never; β = 0.010, 95% CI: −0.007 to 0.027 for food insecurity at ≥ two time points vs. never, Model 3).

Table 2 provides estimates and 95% CIs for the association between food insecurity intensity from 2004 to 2013 and subsequent memory function and rate of decline. Compared to those who never experienced intense food insecurity, individuals experiencing a higher intensity of food insecurity at one time point (β = −0.080, 95% CI: −0.158 to −0.003, p = 0.043) and ≥ two time points (β = −0.271, 95% CI: −0.466 to −0.076, p = 0.006) had lower memory function at HAALSI baseline in 2014/15 (Model 1), while after additionally adjusting for childhood and adulthood socioeconomic status, the estimates were systematically attenuated with 95% CIs crossing the null (β = −0.012, 95% CI: −0.086 to 0.062, p = 0.744, one time point vs. never; β = −0.154, 95% CI: −0.338 to 0.028, p = 0.107, ≥ two time points vs. never; Model 3). Food insecurity intensity was not associated with a subsequent rate of memory decline (β = 0.006, 95% CI: −0.009 to 0.022 for food insecurity intensity at one time point vs. never; β = −0.001, 95% CI: −0.040 to 0.038 for food insecurity intensity at ≥ two time points vs. never, Model 3). Results from sensitivity analyses that incorporated imputed longitudinal food insecurity measures and inverse probability weights were like our main findings (online suppl. Tables 5–6).

Discussion

Using data from a large, population-representative longitudinal study, we observed an improvement in food security from the period 2004 to 2013 among adults aged ≥30 years in this low-income, rural sub-Saharan African setting. These findings are consistent with other research from Agincourt demonstrating that socioeconomic conditions in this region have improved post-Apartheid [35, 41–43]. We found that mid-life household food insecurity was associated with lower memory function but not the subsequent rate of decline in later life. Although our estimates were imprecise potentially due to limited statistical power, we observed strong magnitudes of associations between food insecurity exposures and memory function in 2014/15. The effect sizes for food insecurity at one time point and food insecurity intensity at two or more time points were, respectively, equivalent to chronological aging-related memory declines of 3 years and 5 years. These findings suggest that reducing food insecurity could be an important intervention target to preserve cognitive health during aging in this setting.

Comparison with Existing Studies

Consistent with existing findings, we found that food insecurity may contribute to lower memory function in later life, although estimates in our study and many of these prior studies were imprecise with 95% CI crossing the null [3, 8, 44, 45]. The magnitudes of the observed associations in our study are larger than those observed among the general older adult population in the USA, where a prior study found that the effect size of food insecurity was similar to 0.7 years of memory aging [45]. These findings indicate potential effect modification of this relationship by contextual differences between countries, perhaps pointing to differences in social safety nets. For example, low-income individuals in HICs often have access to more society-wide or governmental food assistance programs [46, 47], which may help attenuate the association between food insecurity and memory function by alleviating hunger, malnutrition, and psychological stress [48, 49].

Findings on the association between food insecurity and the rate of memory decline have been scarce and conflicting. The observed null associations between food insecurity exposures and the rate of memory decline in our study are consistent with those in several existing studies [2, 44]. However, our findings are contradictory to those observed in three US studies, which observed a faster rate of memory decline among food insecure individuals compared to those who did not experience food insecurity [5, 7, 45], although their observed associations were small in magnitude. For example, Lu et al. [5] used data from 12,069 middle-aged and older adults in the USA, finding that food insecurity contributed to the equivalent of 0.67 excess years of memory aging over a 10-year period. The association between food insecurity and the rate of memory decline may be modest in magnitude, as the experience of food insecurity may act as a chronic psychosocial stressor. Its effect may accumulate over time to induce higher levels of inflammation, leading to accelerated memory decline as one age [5, 12, 13, 50, 51]. Therefore, the association between food insecurity and the rate of memory decline may be sensitive to attrition during the follow-up and require a larger sample size and longer periods of follow-up to estimate precisely.

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Table 1. Baseline characteristics by food insecurity from 2004 to 2013, Agincourt HDSS-HAALSI, Agincourt, South Africa, 2004–2022

Baseline characteristic in 2004	Total (*N* = 3,186)	Food insecurity from 2004 to 2013		
		never (*n* = 1,545)	1 time point (*n* = 1,097)	≥2 time points (*n* = 544)
Age, years, mean (SD)	53.03 (12.87)	53.85 (13.02)	52.94 (12.91)	50.89 (12.11)
Age, years, range	30–96	30–96	30–91	30–94
Female (vs. male)	1,803 (56.59)	852 (55.15)	627 (57.16)	324 (59.56)
Country of birth, *n* (%)				
South Africa	2,286 (71.75)	1,143 (73.98)	771 (70.28)	372 (68.38)
Mozambique and other	900 (28.25)	402 (26.02)	326 (29.72)	172 (31.62)
Parents were in a union when participant was born (yes vs. no), *n* (%)	2,988 (93.81)	1,454 (94.17)	1,026 (93.53)	508 (93.38)
Parent died before participant was 18 years old (no vs. yes), *n* (%)	2,803 (87.98)	1,361 (88.09)	968 (88.24)	474 (87.13)
Father's occupational skill level when the participant was a child, *n* (%)				
Lower-skill occupation	2,305 (72.35)	1,121 (72.56)	794 (72.38)	390 (71.69)
Higher-skill occupation	185 (5.81)	96 (6.21)	56 (5.10)	33 (6.07)
Other	368 (11.55)	177 (11.46)	125 (11.39)	66 (12.13)
Unknown	328 (10.30)	151 (9.77)	122 (11.12)	55 (10.11)
Self-rated childhood health, *n* (%)				
Very good	2,229 (70.01)	1,092 (70.77)	762 (69.46)	375 (68.93)
Good	548 (17.21)	270 (17.50)	183 (16.68)	95 (17.46)
Moderate	199 (6.25)	87 (5.64)	69 (6.29)	43 (7.90)
Bad	111 (3.49)	49 (3.18)	44 (4.01)	18 (3.31)
Very bad	97 (3.05)	45 (2.92)	39 (3.56)	13 (2.39)
Education, *n* (%)				
No formal education	1,463 (46.04)	688 (44.70)	508 (46.39)	267 (49.08)
Some primary (1–7 years)	1,125 (35.40)	514 (33.40)	405 (36.99)	206 (37.87)
Some secondary (8–11 years)	356 (11.20)	180 (11.70)	122 (11.14)	54 (9.93)
Secondary or more (12+ years)	234 (7.36)	157 (10.20)	60 (5.48)	17 (3.12)
Can read and/or write (vs. cannot read or write), *n* (%)	1,830 (57.47)	926 (59.97)	613 (55.93)	291 (53.49)
Marital status, *n* (%)				
Married/cohabiting	2,130 (66.96)	1,093 (70.88)	704 (64.29)	333 (61.21)
Separated/divorced	268 (8.43)	105 (6.81)	99 (9.04)	64 (11.76)
Single	236 (7.42)	103 (6.68)	79 (7.21)	54 (9.93)
Widowed	547 (17.20)	241 (15.63)	213 (19.45)	93 (17.10)
Household asset-based wealth index, *n* (%)				
1 (poorest)	554 (17.85)	224 (14.87)	201 (18.73)	129 (24.62)
2	588 (18.95)	219 (14.54)	226 (21.06)	143 (27.29)
3	635 (20.46)	303 (20.12)	226 (21.06)	106 (20.23)
4	642 (20.69)	320 (21.25)	223 (20.78)	99 (18.89)
5 (richest)	684 (22.04)	440 (29.22)	197 (18.36)	47 (8.97)
Occupation skill level, *n* (%)				
Non-employment	1,989 (64.45)	901 (60.31)	719 (67.64)	369 (69.75)
Lower-skill occupation	865 (28.03)	436 (29.18)	289 (27.19)	140 (26.47)
Higher-skill occupation	232 (7.52)	157 (10.51)	55 (5.17)	20 (3.78)
Memory z-score in 2014/2015, mean (SD)	−0.066 (0.969)	0.002 (1.013)	−0.147 (0.945)	−0.096 (0.870)

Missing rate for covariates ranged from 0.03% for parents was in a union when the participant was born, 0.05% for can read and/or write, 0.06% for self-rated health, 0.16% for marital status, 0.425% for education, 2.61% for household asset-based wealth index, to 3.13% for occupation skill levels.

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Table 2. Mixed-effects linear regression analyses of food insecurity from 2004 to 2013 and latent memory z-scores from 2014 to 2022, Agincourt HDSS-HAALSI, Agincourt, Mpumalanga, South Africa

	Model 1		Model 2		Model 3	
	Coef. (95% CI)	*p* value	Coef. (95% CI)	*p* value	Coef. (95% CI)	*p* value
Food insecurity from 2004 to 2013 (*N* = 3,186)						
Years of follow-up	−0.032 (0.048 to −0.016)	<0.001	−0.032 (−0.048 to −0.016)	<0.001	−0.032 (−0.048 to −0.016)	<0.001
Food insecurity 2004–2013						
Never	ref.		ref.		ref.	
One time point	−0.152 (−0.219 to −0.085)	<0.001	−0.148 (−0.215 to −0.082)	<0.001	−0.095 (−0.159 to −0.032)	0.004
≥2 time points	−0.164 (−0.249 to −0.079)	<0.001	−0.162 (−0.246 to −0.078)	<0.001	−0.062 (−0.143 to 0.019)	0.131
Food insecurity 2004–2013 × years of follow-up						
One time point	0.011 (−0.002 to 0.025)	0.107	0.011 (−0.003 to 0.025)	0.121	0.011 (−0.003 to 0.025)	0.122
≥2 time points	0.010 (−0.007 to 0.027)	0.250	0.009 (−0.008 to 0.026)	0.285	0.010 (−0.007 to 0.027)	0.244
Food insecurity intensity from 2004 to 2013 (*N* = 3,169)						
Years of follow-up	−0.027 (−0.042 to −0.012)	<0.001	−0.027 (−0.042 to −0.012)	<0.001	−0.028 (−0.043 to −0.013)	<0.001
Food insecurity intensity						
Never	ref.		ref.		ref.	
One time point	−0.080 (−0.158 to −0.003)	0.043	−0.083 (−0.159 to −0.006)	0.035	−0.012 (−0.086 to 0.062)	0.744
≥2 time points	−0.271 (−0.466 to −0.076)	0.006	−0.275 (−0.468 to −0.083)	0.005	−0.154 (−0.338 to 0.028)	0.107
Food insecurity intensity × years of follow-up						
One time point	0.006 (−0.009 to 0.022)	0.431	0.006 (−0.010 to 0.022)	0.459	0.006 (−0.009 to 0.022)	0.398
≥2 time points	0.004 (−0.036 to 0.043)	0.859	0.003 (−0.036 to 0.042)	0.892	−0.001 (−0.040 to 0.038)	0.967

Model 1 adjusted for baseline age, sex, and country of birth. Model 2 additionally adjusted for having parents in a union when the respondent was born, having a parent who died before the respondent was aged 18, father's occupational skill level during childhood, and self-rated health in childhood. Model 3 additionally adjusted for marital status, the highest level of education, self-reported literacy, household asset-based wealth index, and occupation skill level in 2004. The meaning of the effect sizes for each of the food insecurity exposure categories was determined by comparing the magnitudes of the estimates for each food insecurity exposure group to the main effect of "years of follow-up," which reflects the annual rate of memory decline among individuals who did not experience food insecurity and are in the reference categories of all other covariates.

Measurement differences in the construct of food insecurity between our study and previous studies may also contribute to conflicting findings. The Agincourt HDSS measures whether households have enough food to eat, which is a relatively severe form of food insecurity. This measure is similar to the "very low food security" category used by the US Department of Agriculture, defined as "reports of multiple indications of disrupted eating patterns and reduced food intake" [52]. The measure used in the Agincourt HDSS is different from indicators derived from other experience-based scales used in several research studies, such as the Household Food Insecurity Access Scale (HFIAS), which assesses multidimensional food insecurity incorporating access to high-quality and diverse food, anxiety and uncertainty over the food supply, and insufficient food intake as well as its physical consequence [53]. The HFIAS has been used to measure the prevalence of multidimensional household food insecurity in South Africa in the General Household Survey, indicating a marginal improvement from 24% in 2010 to 21% in 2021 [22]. We may have only been able to capture more extreme food insecurity in a binary fashion, despite the longitudinal nature of our food insecurity measures.

Limitations and Strengths

This study has limitations. First, our findings may be subject to unmeasured confounding bias from early-life health conditions. However, early-life health conditions would most likely affect mid-to-later-life household food insecurity through socioeconomic status, which we accounted for at baseline as best as possible using five indicators (education, literacy, marital status, household asset-based wealth index, and occupation). Second, there could be time-varying confounders that could also be mediators on

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the causal pathway between food insecurity and cognitive function, such as depressive symptoms, which we were unable to control for as they were not measured in the Agincourt HDSS. Third, our measures of food insecurity at the household level may not accurately reflect individual level exposure, especially given that women may sacrifice their own quantity and quality of food for their children due to gender norms in caregiving [38]. Further research that measures food insecurity at individual level is warranted. Moreover, the self-reported data on food insecurity could lead to misclassified food insecurity status, which may distort the estimates for the categorical exposure variables in directions that are difficult to predict [54]. Finally, we were unable to measure food insecurity in a multidimensional manner as has been done in prior studies [2, 7, 55]. Our measure of food insecurity only captured one restrictive dimension of food insecurity (i.e., food insufficiency) and may have missed relevant aspects of food insecurity in this study setting.

This study has notable strengths. To the best of our knowledge, this is one of the first longitudinal studies on the association between food insecurity and cognitive aging in a low-income, rural South African context. We utilized data from a large, population-representative sample of adults aging from mid- to later life, with longitudinal, repeated measures of food insecurity. We used a high-quality assessment of episodic memory adapted from the US Health and Retirement Study [31]. Episodic memory is highly sensitive to aging-related change and is clinically relevant as one of the first cognitive domains affected by ADRD [56]. This study provides empirical evidence from a population that is rapidly aging yet under-represented in global dementia research.

Conclusion

In this low-income, rural South African setting, food insecurity over 9 years in mid-life was associated with lower memory function but not rate of decline over time in later life. Longitudinal studies with a larger sample size and multidimensional measures of food insecurity should be conducted to further explore this relationship across diverse populations and settings.

Statement of Ethics

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. 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. Written informed consent is 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 at each visit.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Funding Sources

This work was supported by the National Institute of Aging of the National Institutes of Health (Grant No. R01AG069128 and R01AG070953). The funder had no role in the design, data collection, data analysis, and reporting of this study.

Author Contributions

X.Y. and L.C.K. designed the study. X.Y. performed data analysis and wrote the first draft of the manuscript. A.G., R.C., C.W.K., R.G.W., D.T.B., M.T.F., S.M.T., K.K., and M.S.R. contributed to data collection and results interpretation. All authors provided critical review for important intellectual content of the manuscript and approved of the final manuscript for submission.

Data Availability Statement

The de-identified HAALSI data are publicly available at https://haalsi.org/data. The de-identified Agincourt HDSS data may be accessed through completion of an online data request form and data use agreement at https://data.agincourt.co.za/index.php/home.

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