REVIEW

Food Insecurity and Cognitive Function in Middle to Older Adulthood: A Systematic Review

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ABSTRACT

Food insecurity (FI) may limit cognitive functioning during aging. The goal of this systematic review was to summarize existing evidence linking FI and general or specific cognitive functions in middle and older adulthood. A systematic search of human studies published between 1 January 2000 and 30 April 2018 was conducted in PubMed, PsycINFO, and CAB Direct. Four independent reviewers assessed the eligibility of identified articles and conducted data extraction and data quality assessment. Ten studies were included in the review, including 1 cluster-randomized controlled trial, 2 longitudinal studies, and 7 cross-sectional studies. Three studies reported the association between early-life FI experience and a global cognitive function measure. Nine studies reported later-life FI experience in relation to global or specific cognitive functions. The results suggest an adverse association between FI experienced in early or later life and global cognitive function; and between later-life FI and executive function and memory. Findings from the review are preliminary because of sparse data, heterogeneity across study populations, exposure and outcome assessments, and potential risk of bias across studies. Future studies are recommended to better understand the role of FI in cognitive function, with the goal of identifying possible critical windows for correction of FI in vulnerable subpopulations to prevent neurocognitive deficit in adulthood. *Adv Nutr* 2020;11:667–676.

Keywords: food insecurity, global cognitive function, cognitive impairment, executive function, memory, adults, systematic review

Introduction

Food insecurity (FI) is defined as limited access to adequate food due to a lack of money and other resources (1). Globally, the number of undernourished people or those facing chronic FI has been rising, from 785 million in 2015 to 822 million in 2018 (2). While low- and middle-income countries have larger proportions of the world's undernourished populations than Western countries, FI remains an important problem in the West. In the United States, about 11% of households were identified as food insecure in 2018 (1). Inequality in access to food is related to the development of many chronic diseases (3–7), including impaired cognitive function in adulthood.

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Address correspondence to MN (e-mail: muzi.na@psu.edu).
Abbreviations used: BPRHS, Boston Puerto Rican Health Study; FI, food insecurity; FS, food secure; HFSSM, Household Food Security Survey Module; LFS, low food security; MMSE, Mini-Mental State Examination; VLFS, very low food security.

FI is considered one of the multiple impediments that could accelerate cognitive decline during aging, a process that is thought to begin as early as in one's 20s and 30s (8). At least 2 mechanistic pathways, unhealthy eating patterns and mental distress, may explain the connection between FI and cognitive decline during aging. Previous research suggests that dietary behavior change associated with food hardship can play an important role in cognitive performance (9). FI is associated with poor diet quality, including a lower intake of nutrient-rich vegetables and fruit (10), and low adherence to healthy eating patterns (11). This decrease in diet quality may predict faster cognitive decline (12–14). FI may also increase stress (15–18), which has the potential to impact brain structure and cognition throughout the lifespan (19). FI contributes to the cumulative physiologic wear and tear on the body, known as allostatic load, through neuroendocrine and inflammatory disturbances (20). Elevated cortisol (a stress hormone) (21) and systemic inflammation (22) have previously been associated with decreased cognition in middle-to-older adulthood.

The impact of FI on neurocognition during the course of brain aging may vary, depending on when the adversity

occurs. In addition, the extent to which FI contributes to changes in neurocognition in adults, and which specific cognitive functions may be most susceptible, remains unclear. The goal of this systematic review was to summarize the existing evidence linking FI and cognitive function in middle-aged and older adults.

Methods

We systematically searched PubMed, PsycINFO, and CAB Direct databases of peer-reviewed journal articles published between 1 January 2000 and 30 April 2018. A combination of relevant indexing terms (Medical Subject Heading or MeSH for PubMed; Thesaurus terms for PsycINFO and CAB Direct) and text words were used to identify full articles investigating the association between FI and cognitive function. The exposure of interest was FI, measured with validated perception-based scales, or subscales that focused on food access. FI experienced between birth and age 18 y was referred to as "early-life FI"; FI experienced in middle or older adulthood was referred to as "later-life" FI. The primary cognitive outcomes of interest included global cognitive function, specific subdomains of cognitive function, cognitive impairment, cognitive decline, neurocognitive disorders, and dementia in middle-aged and older adults. To be included in our analysis, studies must have included human participants, been published in English, and must have been randomized controlled trials or observational studies with longitudinal, case-control, or cross-sectional designs. Articles were excluded if they were published in languages other than English, of if they were reviews, commentaries, or abstracts, with no access to the full paper. Studies with only indirect measures of FI (poverty, participation in food assistance programs, or dietary proxies) were excluded. Studies that only reported associations between FI and behavioral or psychosocial outcomes were also excluded. In addition, studies in which the sample comprised individuals with a specific disease were excluded. The search strategies applied in PubMed, PsycINFO, and CAB Direct can be found in **Supplemental File 1**.

Four independent reviewers (ND, NJ, DX, JH) conducted screening of the titles and abstracts, eligibility assessment, data extraction and data quality assessment. During screening, eligibility assessment, and data quality assessment, the identified articles were read and reviewed independently by 2 reviewers. Any discrepancy between the 2 reviewers was resolved through discussion among the research group (MN, ND, NJ, DX, JH) until consensus was reached. Data extraction was done by the 4 reviewers, in pairs, and was checked and combined by 1 researcher (MN). The principal summary association measures were difference in means (β), difference-in-differences, and odds ratios. Other data extracted included study design, sample size, description of source and study population, follow-up period (if longitudinal studies), FI measure and scale used, cognitive outcome measure and methods used, and variables included in statistical adjustment. Following the recommendation that a systematic review use tools for assessing data quality and bias in observational studies (23), we used a published checklist to qualitatively evaluate the study quality. This checklist included collecting and synthesizing information on the description, sampling, measurement, data analysis and interpretation of results, for all included studies (24). Study quality data were extracted by two independent reviewers and compared and discussed by the group to resolve any discrepancies. Study quality data are presented in **Supplemental Tables 1** and **2**.

Results

Study selection

The combined search resulted in 494 published articles from the 3 databases, among which 92 were duplicates (**Figure 1**). Title and abstract screening excluded 367 articles, leaving 35 articles for eligibility assessment through full-text reading. Of these, 25 were excluded based on the inclusion and exclusion criteria. Specific reasoning for exclusion decisions is shown in Figure 1. In total, 10 studies were included for final qualitative synthesis.

Study characteristics

Table 1 presents the characteristics of the included studies, grouped by timing of FI experience. One study (25) reported the association between both early- and later-life FI and cognitive function. The early- and later-life FI results are presented separately, in Table 1. In sum, 3 studies (25–27) reported the association between early-life FI and cognitive function, and 8 studies (25, 28–34) reported later-life FI in relation to cognitive function. Among the 10 included studies, 5 were conducted in the United States and 5 were conducted in lower- and middle-income countries (Burkina Faso, India, Malaysia, Mexico, South Africa). There were 2 longitudinal studies (follow-up periods were 2 and 16 years, respectively), 7 cross-sectional studies, and 1 cluster-randomized controlled trial, which examined the intervention-related change in FI in relation to change in cognitive function. The sample size of included studies ranged from 350 to 6105.

FI assessment

In all 3 studies that assessed early-life FI, researchers used a single-item question to assess whether or not the individual went without enough food to eat during childhood (25–27). Among the 7 studies that assessed later-life FI, 4 applied the USDA Household Food Security Survey Module (HFSSM) (35), using either the 6-item short form (32) or the 10-item adult module (28, 30–32) to assess FI in the previous 12 mo. Two studies applied similar 9-item scales, with modified questions from the HFSSM, to assess current FI (25) or FI in the previous 3 mo (34). Two other studies applied a 1- or 2-item scale to assess whether the participant had experienced hunger in the previous 12 mo (29, 33).

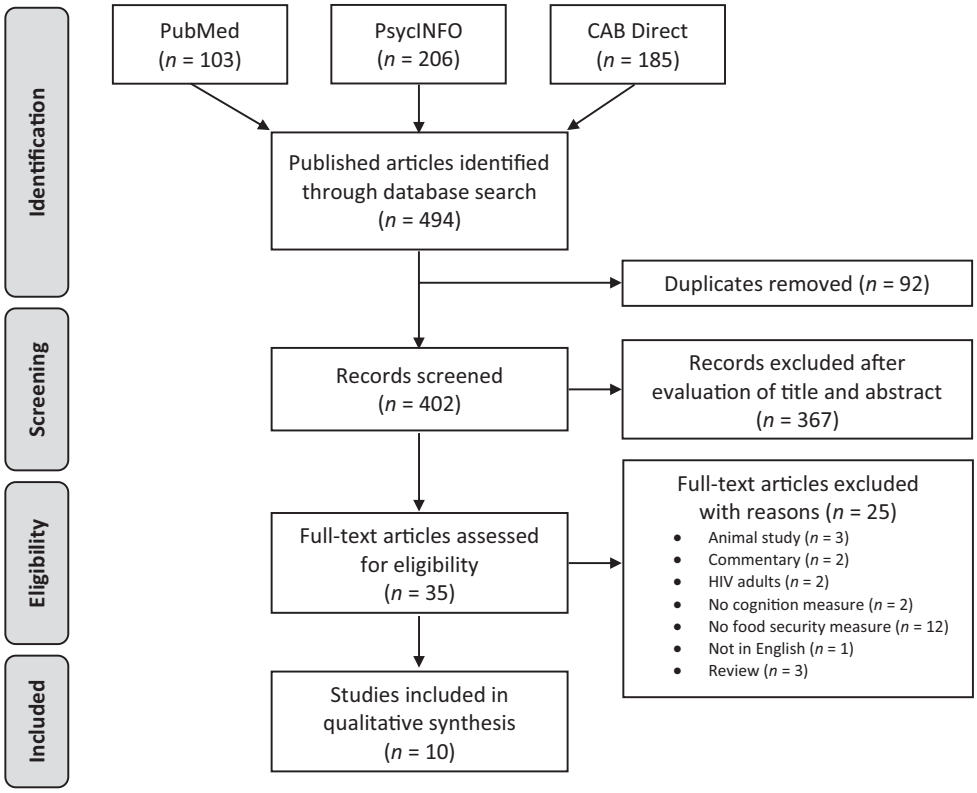

FIGURE 1 PRISMA flow diagram for systematic review.

Cognitive function assessment

All included studies reported test-based cognitive functioning outcomes, and a range of instruments was used for assessment of cognitive functioning in adults (Table 1). Global cognitive function was assessed with the Mini-Mental State Examination (MMSE) alone (28, 30, 32), with a battery of cognitive tests including the MMSE (27), Legane's cognitive test (25), the Geriatric Mental State-Automated Geriatric Examination for Computer Assisted Taxonomy (26), or with predefined criteria for mild cognitive impairment, based on both objective cognitive tests and subjective measures (33). Executive function was assessed with a factor score derived from a set of tests in 2 studies (28, 30), animal naming as a measure of verbal fluency in 1 study (29), and visuospatial and motor speed of processing with the Digit Symbol Substitution Test in another study (31). Memory was reported in 4 studies, each of which included at least a word list learning test (28–30, 34). Attention was only reported in 1 study, using a factor score derived from a number of tests (36).

Early-life FI and global cognitive function

Three studies examined early-life FI and global cognitive function in older adults (**Table 2**). Barnes et al. (27) followed 6105 older residents (mean age = 74.9 y) in the Chicago Health and Aging Project for up to 16 y and found that early-life FI was associated with poorer global cognitive function score at baseline, in non-Hispanic whites. After adjusting for age, sex, current height, adversity indicators in early life (including cognitive, financial, and health indicators), time, and the interaction of each variable with time, the cognitive score at baseline remained 0.197 SD lower in white adults with early-life FI, when compared to the cognitive score of those who had enough food in childhood. In contrast, however, FI experienced at a young age among African Americans was associated with slower cognitive decline [time and early-life FI interaction: 0.021 (0.008); $P < 0.05$] than among those without FI. Cross-sectional associations were reported in 2 international studies. In Burkina Faso, Onadja et al. (25) found that early-life hunger was associated with almost twice the odds of cognitive impairment (OR: 1.80; 95% CI: 1.06, 3.06) in 981 adults aged >50 y, who participated in a local surveillance health survey. The association between early-life hunger and cognitive impairment was identified using a multivariable model, including sex, age, ethnicity, current health, education level in childhood, marital status, high blood pressure, and BMI in old age as controlled variables. In a national survey of 2745 adults aged ≥60 y, Momtaz et al. (26) reported that early-life FI was associated with 1.8 times the odds of dementia (95% CI: 1.13, 2.92) after adjusting for age, sex, marital status, ethnicity, place of residence, and education.

Later-life FI and global and specific cognitive functions

Five studies (25, 28, 30, 32, 33) reported the relation between later-life FI and global cognitive function, including 1 (30) that reported a longitudinal relation between FI and cognitive

TABLE 1 Study characteristics and the effect of food insecurity on cognitive function of included studies[1]

Author, year, country	Study design	Sample size	Source of population (study year), mean age/age group at outcome measurement	Follow-up, y	Exposure measure	Outcome measure (scale/methods)	Effect measure[2]	Level of adjustment[3]
Early-life food insecurity experience								
Barnes et al. (27), 2012, US	Longitudinal	6105	The Chicago Health and Aging Project (1993–2009), 73.9 y (African Americans), 76.6 y (white), 3-y intervals up to 16 y	16 y	1-item early-life FI question "not enough food to eat at young age"	Global cognitive function (2 episodic memory tests, SDMT, MMSE)	In African Americans, early-life FI was not significantly associated with cognitive function at baseline ($\beta = -0.029$, SE = 0.056, $P > 0.05$), but was associated with slower rate of cognitive decline (time and not enough food interaction term = 0.021, SE = 0.008, $P < 0.01$). In whites, early-life FI was associated with poorer cognitive function at baseline ($\beta = -0.197$, SE = 0.086, $P < 0.05$), but was not associated with rate of cognitive decline (time and not enough food interaction term = 0.006, SE = 0.016, $P > 0.05$)	++
Onadja et al. (25), 2013, Burkina Faso	Cross-sectional	981	The Ouagadougou Health and Demographic Surveillance Baseline Survey (2010), ≥50 y	—	1-item early-life FI question "any hunger by 15 y"	Global cognitive impairment (LCT)	Early-life hunger was associated with increased odds of cognitive impairment (OR: 1.80; 95% CI: 1.06, 3.06). No association between early-life hunger and the continuous cognitive score ($\beta = -0.58$, SE = 0.42, NS)	++
Momtaz et al. (26), 2014, Malaysia	Cross-sectional	2745	The Mental Health and Quality of Life of Older Malaysians Survey (2003–2005), 70.5 y/≥60 y	—	1-item early-life FI question "not enough food to eat in childhood"	Dementia (GMS-AGECAT)	Early-life FI was associated with higher odds of dementia (OR: 1.81; 95% CI: 1.13, 2.92)	++
Later-life food insecurity experience								
Gao et al. (28), 2009, US	Cross-sectional	1358	The Boston Puerto Rican Health Study (2004–2009), ~57 y/45–75 y	—	10-item HFSSM	Global cognitive function (MMSE), executive function (letter fluency, figure copying, digits backward, clock drawing, Stroop tests, word list learning), memory (word list learning, recognition, short-term recall, long-term recall), attention (letter fluency, figure copying, digits forward, digits backward)	Compared to FS, VLFS was associated with higher odds of cognitive impairment (OR: 2.28; 95% CI: 1.26, 4.12). No significant association found between FI status and global cognitive function score ($\beta = -0.9$, 95% CI: −1.6, 0.19), but there was a significant trend of decreasing score with progressive FI [mean (SE) in FS, LFS, and VLFS: 23.4 (0.10), 23.3 (0.34), 22.5 (0.35), respectively; P-trend = 0.003]. There was also a decreasing trend of executive function score from FS to LFS and to VLFS [mean (SE) in FS, LFS, and VLFS: −0.004 (0.03), −0.10 (0.11), −0.21 (0.11), respectively, P-trend = 0.003]. No significant trend was observed in memory or attention by FI status [memory score in FS, LFS, and VLFS: 0.03 (0.03), 0.10 (0.12), −0.08 (0.13), respectively, P-trend = 0.32; attention scores: −0.002 (0.03), −0.21 (0.12), 0.04 (0.13), respectively, P-trend = 0.81]	+++
Onadja et al. (25), 2013, Burkina Faso	Cross-sectional	981	The Ouagadougou Health and Demographic Surveillance Baseline Survey (2010), ≥50 y	—	9-item HFIS	Global cognitive impairment (LCT)	No association between household FI and cognitive impairment (OR: 1.00; 95% CI: 0.99, 1.01) or with the continuous cognitive score ($\beta = -0.01$, SE = 0.01, NS)	++
Mayston et al. (29), 2015, India	Cross-sectional	1934	The "Umeed" Project baseline survey in adults for HIV testing (2008–2010), 35 y/≥18 y	—	1-item "ever experienced hunger" past 12 mo	Memory (word list learning) and verbal fluency (animal naming), by CERAD	Adult FI was associated with low delayed recall score (OR: 1.41; 95% CI: 1.05, 1.88), but not low verbal fluency score (OR: 1.00; 95% CI: 0.75, 1.34)	++

(*Continued*)

TABLE 1 (*Continued*)

Author, year, country	Study design	Sample size	Source of population (study year), mean age/age group at outcome measurement	Follow-up, y	Exposure measure	Outcome measure (scale/methods)	Effect measure[2]	Level of adjustment[3]
Wong et al. (30), 2016, US	Longitudinal	597	The Boston Puerto Rican Health Study Cohort (2004–09, 2006–11), 45–75 y, 47–77 y	2 y	10-item adult HFSSM	Global cognitive function (MMSE), executive function (letter fluency, figure copying, digits backward, clock drawing, Stroop), memory (word list learning, recognition, short-term recall, long-term recall)	Compared to FS, global cognitive function declined significantly faster in the VLFS group ($\beta = -0.26$, 95% CI: −0.41, −0.10), but not in the LFS group ($\beta = 0.04$, 95% CI: −0.09, 0.17). *P*-trend = 0.03. Executive function decline was also faster in the VLFS group ($\beta = -0.47$, 95% CI: −0.77, −0.18), but not in the LFS group ($\beta = 0.09$, 95% CI: −0.15, 0.34). *P*-trend = 0.02. Memory decline was not significant between LFS ($\beta = -0.03$, 95% CI: −0.34, 0.23) or VLFS ($\beta = -0.08$, 95% CI: −0.46, 0.30) when compared to the FS group. *P*-trend = 0.66	++++
Frith et al. (31), 2017, US	Cross-sectional	1851	NHANES 1999–2002), 69.8 y/60–85 y	—	10-item HFSSM	Executive function (visuospatial and motor speed-of-processing, by DSST)	Compared to FS, progressive FI was associated with worse executive function (marginally FS: $\beta = -7.7$; 95% CI: −11.9, −3.5; FI without hunger: $\beta = -7.0$; 95% CI: −11.4, −2.6; FI with hunger: $\beta = -14.4$; 95% CI: −23.9, −4.5)	++
Tong et al. (32), 2018, US	Cross-sectional	350	Health Outcomes of People Experiencing Homelessness in Older Middle Age (HOPE HOME) Study (2014–2014), 58.0 y/≥50 y	—	6-item HFSSM	Global cognition (modified MMSE). Mild cognitive impairment defined by NIA-AA as below −1 SD in 1 of the tests (word list learning, digit span forward and backward, animal naming task), AND concern regarding cognitive changes, AND perceived independence in functional abilities; AND absence of dementia	Compared to FS, VLFS was associated with greater odds of cognitive impairment (OR: 2.21; 95% CI: 1.12, 4.35)	++++[4]
Koyanagi et al. (33), 2019, South Africa	Cross-sectional	3672	WHO Study on Global AGEing and Adult Health (SAGE) (2007–2008), 61.4 y/≥50 y	—	2-items "eating less" and "hunger due to lack of food" past 12 mo	—	FI was associated with greater odds of mild cognitive impairment (MCI) (moderate FI: OR: 2.82; 95% CI: 1.65, 4.84; severe FI: OR: 2.51; 95% CI: 1.63, 3.87). For ≥ 65y vs. younger, odds of MCI were similar in the moderate FI group but higher in the severe FI group (moderate FI: OR: 2.76; 95% CI: 1.19, 6.41; severe FI: OR: 3.87; 95% CI: 2.20, 6.81)	++++
Aguila and Casanova (34), 2019, Mexico	Cluster-RCT	2351	Third phase of Supplemental Income Program in Yucatan, Mexico (2008–2009), 77.6 y/≥70 y	6–9 mo	9-item food security scale past 3 mo	Memory (word list learning score, immediate and delayed recall)	In men, FS was a significant mediator of the Supplemental Income Program on both immediate and delayed recall (indirect effect and % effect mediated: 0.024 and 5.9%; $P < 0.05$ immediate recall; 0.032 and 3.4%; $P < 0.05$ delayed recall) mediating 5.9% and 3.4% of the total effect. The mediating effect of FS in women approached significance (indirect effect and % effect mediated: 0.018 and 2.8%; $P < 0.10$ for immediate recall; 0.021 and 2.3%; $P < 0.10$ for delayed recall)	N/A

[1] CERAD, Consortium to Establish a Registry of Alzheimer's Disease; DSST, Digit Symbol Substitution Test; FI, food insecurity; FS, food security; GMS-AGECAT, Geriatric Mental State-Automated Geriatric Examination for Computer Assisted Taxonomy; HFIS, household food insecurity scale; HFSSM, Household Food Security Survey Module; LCT, Legane's cognitive test; LFS, low food security; VLFS, very low food security; MMSE, Mini-Mental State Examination; NIA-AA, National Institute on Aging-Alzheimer's Association; SDMT, Symbol Digit Modalities Test.

[2] NS, not significant with $P \geq 0.05$.

[3] Level of adjustment: O, none; +, child age and/or sex only; ++, additionally adjusted for demographic and socioeconomic variables but not including income/wealth; +++, additionally adjusted for income/wealth/assistance program participation; ++++, additionally adjusted for potential mediators such as parental psychological factors.

[4] Initial controlled variables included a list of demographic and socioeconomic factors, including age, sex, annual income, employment, and depression, and was then reduced by backward selection.

TABLE 2 Direction of associations between food insecurity and cognitive function in middle-aged and older adults[1]

	Early-life FI experience	Later-life FI experience			
	Global cognitive function	Global cognitive function	Executive function	Memory	Attention
Food insecurity is related to better cognitive outcomes	L [Barnes (27)] – African Americans* L [Barnes (27)] – white				C [Gao (28)]
No association			C [Mayston (29)]		
Food insecurity is related to detrimental cognitive outcomes	C [Barnes (27)] – African Americans	L [Wong (30)]*	L [Wong (30)]*	L [Wong (30)]	
	C [Barnes (27)] – white*	C [Gao (28)]*	C [Gao (28)]*	L [Aguila (34)] – men*	
	C [Onadja (25)]*	C [Onadja (25)]	C [Frith (31)]*	L [Aguila (34)] – women	
	C [Momtaz (26)]*	C [Tong (32)]* C [Koyanagi (33)]*		C [Gao (28)] C [Mayston (29)]*	

[1]The first author of the study is presented in the parentheses for simplicity. When associations were reported for multiple levels of food insecurity, only the association between the most extreme level of food insecurity and outcome is presented in the table. C, cross-sectional relation; L, longitudinal relation.
*Significance at 0.05 level.

decline over a 2-y span. Four studies (25, 28, 32, 33) reported cross-sectional relations between FI and cognitive function. Specifically, data from the Boston Puerto Rican Health Study (BPRHS) cohort at baseline and at the 2-y follow-up showed that the 2-y decline in global cognitive function score was significantly faster in the very low food security (VLFS) group, relative to the food secure group ($\beta = -0.26$, 95% CI: −0.41, −0.10). There was also a significant trend of worsened global cognitive decline with progressive FI status (P-trend = 0.03). These statistically significant findings were found even after taking into account demographics (age, sex), socioeconomic factors (education, poverty, acculturation score), lifestyle (smoking status, use of alcohol, physical activity score, healthy eating index), and current health variables (BMI, presence of diabetes, hypertension, apolipoprotein E status, plasma homocysteine, and depression score) (30). Using baseline data from the BPRHS, and adjusting for similar confounders (including age, sex, BMI, education, poverty, acculturation score, smoking, use of alcohol, presence of diabetes and hypertension, plasma homocysteine), Gao et al. (36) reported that individuals with VLFS had twice the odds of cognitive impairment, defined as MMSE score <24 (OR: 2.28; 95% CI: 1.26, 4.12) compared to those who were food secure (FS). A study of 350 homeless adults, aged ≥50 y, also found greater than twice the odds of cognitive impairment in the VLFS, relative to the FS, group (OR: 2.21; 95% CI: 1.12, 4.35), where cognitive impairment was defined as MMSE score <7th percentile, after age and education adjustment (32). In a national sample of 3672 South African adults, aged ≥50 y, moderate (OR: 2.82; 95% CI: 1.65, 4.84) and severe FI (OR: 2.51; 95% CI: 1.63, 3.87) were associated with 2.5–2.8 times higher odds for mild cognitive impairment, defined by poor cognitive test results, concern regarding cognitive changes, perceived independence in functional abilities, and absence of dementia, compared to those with no FI (33). These odds remained significant after adjusting for sex, age, education, wealth, race, physical activity, smoking, alcohol consumption, BMI, and whether or not the individual had diabetes, stroke, hypertension, or depression. Poorer global cognitive scores were also associated with household FI score (range 0–100) in Burkina Faso, but these results did not reach significance ($\beta = -0.01$; SE = 0.01; $P > 0.05$) (25).

Few studies have reported the effect of FI on specific cognitive function domains. Four (28–31) reported the relation between FI and executive function, and all but 1 (29) found significant inverse associations. In the BPRHS, FI was associated with poorer executive function at baseline (36), and with faster 2-y decline in executive function (37). In US national survey data, including 1851 adults between the ages of 60 and 85 y, progressive FI was associated in a dose-response relation with poorer executive function scores, adjusting for age, sex, race/ethnicity, BMI, C-reactive protein, smoking, diabetes status, blood pressure, physical activity, and social support (FS as reference group; marginally FS: $\beta = -7.7$; 95% CI: −11.9, −3.5; FI without hunger: $\beta = -7.0$; 95% CI: −11.4, −2.6; FI with hunger: $\beta = -14.4$; 95% CI: −23.9, −4.5) (31). In a sample of Indian adults, aged ≥18 y, tested for HIV, no directional association was seen between FI and verbal fluency (OR: 1.00; 95% CI: 0.75, 1.34) when age, sex, psychological/cognitive comorbidity, and other psychosocial variables were adjusted.

Four studies (28–30, 34) investigated FI in relation to memory function, and 1 of these (34) reported results separately for men and women. All of the reported point estimates were in the direction of a relation between FI and worse memory outcomes, but not all were statistically significant. In a cluster-randomized controlled trial of a supplemental income program for Mexican adults, aged ≥70 y, improvement in immediate (indirect effect and % effect mediated: 0.024 and 5.9%; $P < 0.05$) and delayed recall scores (0.032 and 3.4%; $P < 0.05$) was partially mediated by improved food security in men. Mediation by improved

food security was marginally significant in women for both immediate recall (0.018 and 2.8%; $P < 0.10$) and delayed recall (0.021 and 2.3%; $P < 0.10$) (34). In a longitudinal analysis of the BPRHS, memory decline between baseline and the 2-y follow-up appeared to be greater in the low food security (LFS) and VLFS groups compared to the FS group, but neither was statistically significant (LFS: $\beta = -0.03$, 95% CI: −0.34, 0.23; VLFS: $\beta = -0.08$, 95% CI: −0.46, 0.30) (30). Similarly, no significant associations between FI and memory were observed at baseline in the BPRHS (28). Mayston et al. (29) found that adults reporting FI tended to have lower scores on the delayed recall test than adults with FS (OR: 1.41; 95% CI: 0.75, 1.34), but this also did not reach significance.

We identified only 1 study that examined FI in relation to attention. In the BPRHS, at baseline, the attention score appeared higher in the VLFS group compared to the FS group ($\beta = 0.04$, $P > 0.05$), but this trend was not significant (P-trend = 0.81).

Discussion

We systematically reviewed 10 studies and found an emerging negative association between FI, experienced at early or later life, and global cognitive function in middle-age and older adults. For specific cognitive functions, sparse but consistent data support an inverse association between later-life FI and executive function and memory. When linking FI with change in cognitive function over time, the early-life and later-life FI effects were inconsistent. Surprisingly, 1 longitudinal study showed racial differences in the association, with food deprivation in childhood associated with greater cognitive decline in non-Hispanic white adults, but with reduced cognitive decline among non-Hispanic blacks. Two other studies demonstrated an association between later-life FI and more severe 2-y cognitive decline, and worse short-term memory, respectively.

The available evidence suggests that the timing of FI may be important in determining the effect of FI on cognitive functioning. FI from gestation to infancy is known to be a critical risk factor for negative neurodevelopmental outcomes (38). Deficits in language ability and communication skills associated with early-life FI exposure may become apparent by the age of 2 y (39, 40). In low- and middle-income countries, pre- and postnatal FI is likely a continuous problem associated with poor maternal diet (41–43) and suboptimal feeding practices (44), which both increase the risk of child malnutrition and growth retardation (45). Cognitive deficits that result from infant and child malnutrition may persist into adolescence and adulthood. A longitudinal study in Barbadian adults followed since childhood reported that an episode of moderate to severe malnutrition in the first year of life, even with complete nutrition rehabilitation in later life, was associated with impaired attention (46) and IQ (47) 40 y after the episode. In our review, studies conducted in Burkina Faso (25) and Malaysia (26) both observed a significant association between reported early-life FI and cognitive impairment in adults. In the United States, FI may alter parenting (48) and feeding practices (48, 49). However, the nutritional consequences of FI in terms of child diet (10) and weight (50) were less consistent. In addition, FI contributes to overall family stress and may act on cognition through caregiver psychological distress (51), variation in early brain development (52), and changes in child mental health (53). Through these indirect diet and stress pathways, FI has been associated with a detrimental impact on the cognitive potential in children (52). This negative association may extend to later-life cognition, as suggested by the consistent cross-sectional associations in this review. The observed protective effect of FI against cognitive decline may be partially explained by complex diet and stress pathways, and may be time- and population-specific. Survival effects in samples of older adults should also be considered when interpreting longitudinal data (27).

In our review, later-life FI was consistently associated with decreased cognitive function in adulthood. Cumulative evidence generated from adults supports associations between FI and both decreased diet quality (10) and increased mental distress (54). It is likely that both poor diet and stress act as mediators underlying the observed FI-impaired cognition relation. A link between FI and obesity has been consistently observed in US adults (50) and has begun to emerge in low- and middle-income countries that are undergoing the nutrition transition (55). Adult obesity is also prospectively associated with impaired global cognition (56) and specific cognitive functions (57, 58), even after controlling for related lifestyle risk factors and the comorbidity of other chronic diseases.

Although the expected directional association in the FI–cognition relation was generally observed, the current synthesis of study findings is still preliminary, because of the heterogeneity of the included studies in terms of study population, exposure, and outcome assessment, as well as potential risk of bias across studies. These limitations are further discussed below.

Heterogeneity in FI measurement was apparent in terms of assessment level (e.g., household, adult, or adolescent) and timeframe (e.g., previous 30 d, previous 12 mo, early childhood). Although a list of common FI experiences that exist across cultures is used to assess FI (59), considerable challenges in FI measurement remain, including capturing multidimensionality and the validity of using cutoffs to define these dimensions (60, 61). These challenges may result in differential measurement errors in low-income compared to high-income countries. Potential recall bias and misclassification may exist in all studies and could be more problematic in studies of adults inquiring about early-life FI using a single question. Such misclassification, if it occurred "non-differentially" by cognitive outcomes, may have led to underestimation of the true association between FI and cognitive function (62). Differential misclassification of FI status may also arise from FI categorization, after using continuous scores (63), a process that was applied in all studies using multiple-item FI scales. Therefore, the direction of bias cannot be assumed to always be toward the null (64). Despite these challenges, it is possible to estimate and

interpret the potential bias in future validity and reliability studies by estimating the mis-measured and "true" values of FI and the degree of differential bias by individual cognitive function status (65). In addition, the timing, intensity, and duration of FI are likely to be important factors in relation to specific cognitive functions. However, none of the included studies had multiple FI measures to examine such effects.

Although most of the assessment instruments were validated, the range of methods used to measure cognitive function poses challenges for comparing and quantitatively summarizing research findings. Longitudinal cognitive decline is a better outcome measure to characterize disease and the brain aging process than cross-sectional comparisons. However, cognitive decline was only measured in 2 longitudinal studies, and the number of outcome assessments and length of follow-up time varied. It was difficult to estimate whether the lack of association between FI and cognitive decline found in some studies resulted from insufficient follow-up time. The majority of studies included in this review were cross-sectional and only measured cognitive function once.

Residual confounding is a likely issue in many of the included studies. For example, among the 10 included studies, 5 did not include a measure of financial constraint as a control variable. Food access insecurity is highly correlated with wealth, but its variance cannot be fully explained by a simple economic proxy (66). Therefore, when interested in the influence of FI independent of wealth, researchers should adjust for the confounding impact of poverty that predicts other unmeasured risk factors that confound the FI–cognitive function relation. Another example of possible residual confounding is lack of adjustment for health conditions that may affect the FI–cognition relation. Presence of hypertension and diabetes predict worse cognitive performance in older adults (67, 68), but these 2 important comorbidities were only considered in 3 out of 10 included studies. Overadjustment is another concern in selected studies, when variables related to diet and/or stress were included in the model as control variables. If the main effects of FI act through compromised diet and/or increased stress, the observed associations may have been even stronger if the studies did not include diet- or stress-related mediators in the model estimation [e.g., plasma homocysteine, a biomarker of vitamin B status (28, 30), healthy eating index (30), depressive symptoms (30, 32) or diagnosed depression (33)].

Five of the included studies were conducted in the United States (including 2 studies using data from the BPRHS cohort) and 5 studies were performed in low- and middle-income settings. Despite the few, heterogeneous studies included, the FI–cognitive function relation seems relatively consistent between the United States and developing settings. Nationally representative samples were used in 3 out of 10 included studies, while the others included specific population subsets, including urban ethnic minorities (27, 36, 37), the poor (25), the homeless (32), and people who sought HIV pre-test counselling (29). In addition, differences in the effect of FI on cognition between subgroups were reported in only 2 studies, which reported differences by race (27) and sex (34). Currently, there is insufficient evidence to identify particular vulnerable populations who may suffer more from neurocognitive deficits if living under FI.

Our findings from this systematic review suggest that FI, experienced in early or later life, is associated with worse global cognition. This suggests that individuals with FI may be at higher risk of experiencing poor cognitive function, highlighting the importance of food policy and interventional strategies that address FI. Alleviating FI may impact the disease burden for this at-risk population, not only in terms of nutrition-sensitive adverse consequences, but also potentially in terms of neurocognitive outcomes. Interpretation of these findings should be made with caution, given the still-sparse evidence, methodologic differences, and limitations in the analysis of the included studies. To further evaluate the complex relation between FI and adult cognitive function, future studies should include longitudinal FI assessment, standardized and longitudinal measures of cognitive outcomes for trajectory evaluation, and stratification analysis by participant characteristics to identify at-risk subgroups.

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