Review

Food Insecurity Is Associated with Cognitive Function: A Systematic Review of Findings across the Life Course

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Abstract: Food insecurity (FI) has negative implications across the life course that include poor health outcomes among both children and adults. However, the behavioral mechanisms by which FI impacts health behaviors are not clear. By understanding how FI is related to cognitive function/brain structure across the life course, we can design more targeted interventions. A systematic literature review was performed by conducting comprehensive database searches in Google Scholar and PubMed. Inclusion criteria required studies to include measures of FI and cognitive function/brain structure in humans. Study sample, design, outcomes, and biases were extracted. In total, 17 studies met the inclusion criteria. Cognitive domains included general cognition ($n = 13$), executive function ($n = 10$), visuospatial abilities ($n = 4$), and verbal memory ($n = 8$). No studies examined brain structure. Most studies (88%) indicated significant inverse associations between FI and cognitive function across all stages of the life course, particularly for general cognition and executive function. Significant inverse associations were observed between FI and either general cognition or executive function among children ($n = 3$) and adults ($n = 12$). All studies considered confounding variables; however, given that all were observational, no causality can be inferred from the findings. These findings indicate that FI is related to lower cognitive function across the life course. Research should explore how changes in food security status impacts cognitive function and brain structure to develop optimal FI interventions and improve cognitive health.

Keywords: food insecurity; hunger; cognitive function; cognition; systematic review

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1. Introduction

Food insecurity involves reduced quality, variety, or desirability of the diet, and can also include disrupted eating patterns with reduced food intake [1]. In 2019, 10.5% of households (13.7 million) in the U.S. experienced food insecurity [2]. Certain groups are at higher risk of experiencing food insecurity, including households with children [3], unmarried people [4], and communities of color [5].

Food insecurity has negative implications across the life course that include negative outcomes among both children and adults [6]. Childhood food insecurity and hunger are linked to poor general health outcomes [7,8]. Food insecurity during childhood may include the onset of mental health struggles with anxiety [9], depression [10], and even suicide ideation [10]. Behavior problems [11] and physical aggression [9] are also related to childhood experiences with food insecurity. Numerous research studies have shown that schoolchildren experiencing household food insecurity have impaired levels of academic performance [12–14]. Adults experiencing food insecurity and hunger also tend to suffer poor health outcomes including heart disease [15], diabetes [16], obesity [15], hypertension [15,16], and sleep problems [17]. Among children and parents, there has been a demonstrated bi-directional relationship between food insecurity and depression [9].

Poor mental health is also associated with food insecurity among adults [10,18] through pathways such as stress [18], anxiety [9], and depression [9].

Extensive research has yielded study findings that elucidate how poverty-related circumstances, such as food insecurity experiences resulting from being low income, incur negative health outcomes among vulnerable children [19] and adults [20]. Past studies have explored the relationship between varying degrees of undernutrition and numerous cognitive and behavioral outcomes. Results indicate inverse associations between these proxy factors and poor cognitive faculty functioning outcomes [21–28]. Researchers have also examined how malnutrition impacts the brain by using magnetic resonance imaging [29] and electroencephalography [29,30]. For example, A case–control study of post-mortem children studied the unique effects of severe undernutrition on neural development, and cases had significantly altered structural development of neural cells when compared with healthy controls [31].

Despite different etiologies, eating disorders (a psychological condition related to health) and food insecurity (a sociological condition related to health) share deficits in food consumption that may produce similar cognitive function outcomes. Past research has determined that anorexia can result in cognitive deficits related to reduced brain volumes [32]. Other studies on eating disorders and cognitive function have yielded contradicting results, as one study found no severe cognitive function impairment among anorexic adolescent females [33], while other research suggested that bulimic and anorexic women incur negative effects on cognitive function [34].

Research on voluntary caloric restriction (e.g., intermittent fasting) has provided additional insights on how food intake impacts cognitive function. Past research findings indicate that periodic caloric restriction can either maintain [35] or impair cognitive function [36]. Additionally, the results from studies examining caloric deprivation are similar to those evaluating caloric restriction, with cognitive function maintained [37,38] or impaired [39]. Some studies have shown working memory improvements with caloric restriction [40], while a systematic review of voluntary experimental fasting showed either impaired or maintained cognitive function among participants [41].

It is possible that food-insecure populations have an overabundance of cheap, less healthful foods. Research has indicated that populations at risk for food insecurity have the double burden of an inadequate intake of key nutrients combined with the overconsumption of high-calorie, low-nutrient foods (sometimes referred to as overnutrition), [42,43] which is often linked with an increased prevalence of obesity and other chronic diseases [44–46]. There is an ongoing movement within the scientific community to examine food insecurity more holistically as nutrition [47], because the quality of food is as important as the quantity of food to promote health and prevent disease [48]. Dietary quality, overnutrition, and obesity have been linked to food insecurity [49–52] and cognitive function [53–56]. However, the literature linking overnutrition and obesity to food insecurity and cognitive health does not seem to be as consistent or robust as the literature on eating disorders and caloric restriction [51,57,58].

With all the relevant extant scholarly literature considered, additional research that can improve the knowledge base regarding the link between food insecurity and cognitive function is essential. Therefore, we conducted a systematic review to more precisely understand this association by specifically focusing on the relationship between food insecurity and cognitive function. Given that cognitive function changes with age, a life course perspective is important for describing such patterns and transitions [59]. Another recent systematic review evaluated similar associations among middle-aged and older adults only and found (1) a positive association between early-life food insecurity and later-life cognitive function impairment, (2) a concurrent positive association between food insecurity and impaired cognitive function, and (3) a significantly faster decline in cognitive function among individuals experiencing the most severe form of food insecurity compared with their food-secure counterparts [60]. Our systematic review expands on Na et al.'s (2020) review by including studies with participants of all ages, while also

examining the validity, bias, and statistical approaches used in each study [60]. We sought to broaden the understanding of how food insecurity and cognitive function are related by critically analyzing the nature of this relationship in study samples spanning the human life course. Understanding how food insecurity is related to cognitive function will help us to better understand the potential neurobiological associations of food insecurity across the life course.

2. Materials and Methods

We performed a systematic review guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines (Figure 1) to investigate the association between food insecurity and cognitive function. Specified inclusion criteria consisted of human studies involving subjects that were either currently or previously experiencing a condition related to food insecurity, which could also have consisted of food insufficiency, food shortage, and/or hunger. Included studies were required to have used a food insecurity measure and either a cognitive function or brain structure measure. Studies from any publication period were included. Exclusion criteria involved case studies; animal studies; and studies investigating malnutrition, eating disorders, or voluntary caloric restriction. We used these terms in the search to capture as many relevant studies as possible. However, while sharing similarities with food insecurity research, studies on malnutrition, eating disorders, and voluntary caloric restriction were excluded because a multitude of studies have already investigated the association between those variables and cognitive function [61–63].

Database searches were conducted in January 2021 using Google Scholar and PubMed to identify all relevant scholarly literature published in any year. The initial search terms for food insecurity (food insecurity, food insufficiency, food hardship, food shortage, hunger, malnourishment, malnutrition, undernutrition, food restriction, caloric restriction, food deprivation, caloric deprivation, eating disorders, and starvation) were paired with cognitive function terms (cognitive function, brain function, executive function, learning, decision making, memory, attention, mild cognitive impairment, psychological development, brain development, neurodevelopment, brain, neurology, neuroimaging, MRI, fMRI, EEG, and MEG). This process included 252 searches in both Google Scholar and PubMed, which totaled 504 searches (see Supplementary Materials Table S1). Two reviewers (MR, NG) screened the titles and abstracts of articles aligning with the selected key search terms, along with inclusion and exclusion criteria. Included studies were then thoroughly reviewed to confirm their inclusion.

A combination of two investigators reviewed each article (MB or MNL, paired with either MR or NG) to subsequently summarize and grade the literature. Key components of each study were summarized, which included the year the data were collected, country of study, dataset origin, sample size, study design, sex and age of study sample, food insecurity measure, cognitive function measure, brain measure, results summary, and confidence intervals. Confidence intervals are essential for validating the accuracy and precision of statistically significant findings [64]. As per the Preliminary Tool for Risk of Bias in Exposure Studies [65], Q-Coh [66], and other tools for grading the strength and quality of a body of evidence [67,68], bias was assessed in each study by evaluating the following: the control and conditional groups were concurrently measured, similarity of groups at baseline, methods used to adjust or avoid selection bias, validity of measures, differential loss of subjects among groups, statistical power, recall bias, confidence interval statistics, missing information, discrepancies, and conflicts of interest. The PRISMA diagram (Figure 1) illustrates the research approach implemented for this systematic review.

Figure 1. PRISMA Diagram– Search Strategy for Systematic Review on Food Insecurity and Cognitive Function.

3. Results

Participant age in the 17 included studies ranged from 9 months [69] to 85 years old [70], with sample sizes ranging from 97 [71] to 11,958 [72]. The 17 studies used a total of six food insecurity measures and 21 cognitive function measures. Observational study designs were used for all 17 studies (Table 1) [69–85]. A cross-sectional design was used in 14 studies [69–81,85], while all three of the longitudinal studies reported significant inverse associations between food insecurity and cognitive function over time [82–84].

Table 1. Characteristics, measures, and outcomes for studies examining food insecurity and cognitive function ($n = 17$).

Authors	Study Design	Year of Data Collection	Country	Sample Size	Participant Demographics	Food Insecurity Measures	Cognitive Function Measures ¹	Food Insecurity and Cognitive Function Findings ²
Alaimo et al. (2001) [73]	Observational, cross-sectional, secondary data	1988–1994	USA	5349	Children; aged 6–11 years old Adolescents; aged 12–16 years old	NHANES III: ‘Sometimes or often not enough food’	WISC-R: Block design and digit span tasks	Food insecurity and executive function/visuospatial abilities: (null)
Barnes et al. (2012) [83]	Observational, longitudinal, primary data	1993–2009	USA	6105	Adults; mean 74.9 years old; 61.8% Black; 60.7% female	One item asking how often participants went without enough food to eat during childhood	MMSE	Food insecurity and general cognition: $\beta = -0.197$ $p < 0.001$
Cohn-Schwartz & Weinstein (2020) [84]	Observational, longitudinal, secondary Data	2009–2013	Europe (Multi-Country)	2131	Adults; mean 76.2 years old; 50% female	Two items: one asking whether the participant ever experienced hunger; one asking when the hunger period occurred	RAVLT; SHARE immediate and delayed word recall; animal naming task; serial sevens test	Food insecurity and impaired general cognition OR = 0.97 95% CI = 0.94–0.99 and verbal memory $\beta = -1.23$ $p = 0.04$
Frith and Loprinzi (2018) [70]	Observational, cross-sectional, secondary data	1999–2002	USA	1851	Adults; 60–85 years old	USDA 18-item Household Food Security Survey Module	DSST	Food insecurity and general cognition: $\beta = -14.4$; 95% CI = -22.3 , -0.3
Gao et al. (2009) [74]	Observational, cross-sectional, primary data	2004–2009	USA	1358	Adults; 45–75 years old; 70% female	USDA 10-item Household Food Security Scale	MMSE; verbal memory test; digit span test	Food insecurity and executive function $\beta = -0.21$ $p = 0.003$ and verbal memory $\beta = 22.7$ $p = 0.04$
Grineski et al. (2018) [72]	Observational, cross-sectional, secondary data	2010–2012	USA	11958	Children; 5–9 years old; 52% White, 13% Black, 25% Hispanic, 4% Asian, 6% other	USDA 18-item Household Food Security Survey Module	Numbers reversed test; 2-step dimensional change card sort test	Food insecurity and executive function: $\beta = -5.20$ $p \leq 0.05$
Hernandez and Jackowitz (2009) [69]	Observational, cross-sectional, secondary data	2001–2006	USA	7900	Children; 9–24 months old	USDA 18-item Household Food Security Survey Module	BSF-R mental scale	Food insecurity and general cognition: $\beta = -1.62$ $p < 0.05$
Hobbs and King (2018) [75]	Observational, cross-sectional, secondary data	1998–2000	USA	2046	Children; 5 years old; 22.5% White; 52.6% Black; 21.6% Hispanic; 3.3% other	USDA 18-item Household Food Security Survey Module	Peabody: PVT-R; W-J letter-word	Food insecurity and general cognition: $\beta = -0.19$ 95% CI = -0.33 , -0.04
Hobkirk et al. (2017) [71]	Observational, cross-sectional, primary data	2010–2014	USA	97	Adults; mean 45 years old; 85% Black; 35% female	HFIAS for Measurement of Food Access: Indicator Guide Version 3	WAIS-III; HVLT; BVMT-R; Stroop test; trail-making test; PASAT-100; NAB digits test; FAS; grooved pegboard test	Food insecurity and general cognition/executive function: (null)

Table 1. Cont.

Authors	Study Design	Year of Data Collection	Country	Sample Size	Participant Demographics	Food Insecurity Measures	Cognitive Function Measures ¹	Food Insecurity and Cognitive Function Findings ²
Koyanagi et al. (2019) [76]	Observational, cross-sectional, secondary data	2007–2008	South Africa	3672	Adults; mean 61.4 years old; 74.2% Black, 8.2% White, 16.5% other; 56% female	Two items adapted from NHANES	CERAD; WAIS-III; Animal Naming Task	Food insecurity and impaired general cognition: OR = 2.41 95% CI = 1.63, 3.87
Mayston et al. (2015) [77]	Observational, cross-sectional, primary data	2008–2010	India	1934	Adults; mean 35 years old; 53% female	One item asking if participants had ‘ever experienced hunger due to a lack of money’	Word-list learning memory task; animal naming verbal fluency task	Food insecurity and impaired verbal memory: OR = 1.41 95% CI = 1.05, 1.88
Momtaz et al. (2015) [78]	Observational, cross-sectional, secondary data	2003–2005	Malaysia	2745	Adults; 60+ years old	One item asking if participants had ‘enough food to eat’	GMS-AGECAT: Malaysian-adapted	Food insecurity & impaired general cognition: OR = 1.81 95% CI = 1.13, 2.92
Onadja et al. (2013) [79]	Observational, cross-sectional, secondary data	2010	Burkina Faso	981	Adults; 50+ years old; 52.6% female	Measure examining ‘food availability uncertainty,’ ‘food intake reduction,’ and ‘totally lacking food’	LCT	Food insecurity and impaired general cognition: OR = 1.80 95% CI = 1.06, 3.06
Portela-Parra and Leung (2019) [80]	Observational, cross-sectional, secondary data	2011–2014	USA	1823	Adults; 60+ years old; 54% female; 42.7% Non-Hispanic White, 22.9% Non-Hispanic Black, 25.8% Hispanic, 8.6% Non-Hispanic other	USDA 10-item Adult Food Security Survey Module	CERAD: word learning subtest, delayed word recall; AFT, DSST	Food insecurity and general cognition $\beta = -0.24$ 95% CI = -0.33 , -0.15 , executive function $\beta = -0.13$ 95% CI = -0.25 , -0.002 , and verbal memory: $\beta = -0.14$ 95% CI = -0.26 , -0.01
Tan et al. (2020) [85]	Observational, cross-sectional, secondary data	2013–2015	USA	1346	Adults; median 49.6 years old; 68.1% Black, 10.9% White, 16.4% Hispanic; 4.6% other	USDA 18-item Household Food Security Survey Module	Letter–number span task, Stroop test, symbol digit modalities test, trail-making test Part B, HVLT, COWAT	Food insecurity & executive function: $\beta = -1.45$ $p \leq 0.01$
Tong et al. (2018) [81]	Observational, cross-sectional, secondary data	2013–2014	USA	250	Adults; mean 58 years old; 79.7% Black, 10.9% White, 4.6% Hispanic/Latino; 22.9% female	USDA Household Food Security Survey Module 6-item Short Form	MMSE	Food insecurity and impaired general cognition: OR = 2.21 95% CI = 1.12, 4.35

Table 1. Cont.

Authors	Study Design	Year of Data Collection	Country	Sample Size	Participant Demographics	Food Insecurity Measures	Cognitive Function Measures ¹	Food Insecurity and Cognitive Function Findings ²
Wong et al. (2016) [82]	Observational, longitudinal, primary data	2004–2009	USA	597	Adults; 45–75 years old; 68.3% female	USDA 10-item Household Food Security Survey Module	MMSE, 16-word learning list, digit span test (forward and backward), Stroop test, verbal fluency test, clock drawing test, figure copying	Food insecurity and general cognition $\beta = -1.20$ 95% CI = $-2.19, -0.20$, executive function $\beta = -4.67$ 95% CI = $-8.52, -0.85$, and visuospatial abilities: $\beta = -6.18$ 95% CI = $-8.92, -3.43$

¹ FT: Animal Fluency Test; BSF-R: Bayley Short Form—Research; AUDIT: Alcohol Abuse Disorders Inventory Test; BVM-R: Brief Visuospatial Memory Test—Revised; CERAD: Consortium to Establish a Registry for Alzheimer’s Disease; COWAT: Controlled Oral Word Association Test; DSST: Digit Symbol Substitution Test; GMS-AGECAT: Geriatric Mental State—Automated Geriatric Examination for Computer-Assisted Taxonomy; HFIAS: Household FI Access Scale; HVLT: Hopkins Verbal Learning Test—Revised; LCT: Leganés Cognitive Test; MCI: Mild Cognitive Impairment; MMSE: Mini Mental State Examination; NAB: Neuropsychological Assessment Battery; NHANES: National Health and Nutrition Examination Survey; PASAT-100: Paced Auditory Serial Addition Task-100; Peabody PVT-R: Peabody Picture Vocabulary Test—Revised; RAVLT: Rey’s Auditory Verbal Learning Test; SHARE: Survey of Health, Ageing, and Retirement in Europe; WAIS-III: Wechsler Adult Intelligence Scale; WISC-R: Wechsler Intelligence Scale for Children—Revised; W-J Letter-Word: Woodcock–Johnson Test of Achievement Letter–Word Identification Subtest ² β = standardized beta coefficient; b = unstandardized beta coefficient; OR = odds ratio; CI = confidence interval.

The findings from 15 of the 17 studies suggest a significant inverse association between food insecurity and cognitive function [69,70,72,74–85]. The significant inverse relationship between food insecurity and cognitive function was reported in three of the four studies among children [69,72,75] and 12 of the 13 studies among adults [70,74,76–85]. The odds ratios reported in five studies indicated that middle-aged and older adults experiencing food insecurity have significantly greater odds of demonstrating impaired general cognition compared with their food-secure counterparts [76,78,79,81,84].

Four studies assessed food insecurity and cognitive function in children [69,72,73,75]; ranging from toddlers (9–24 months) [69] to teens (13–16 years) [73]. Among children, food insecurity was reported to be inversely associated with general cognition [69,75] and executive function [72]. Hernandez and Jacknowitz (2009) found that maternal food insecurity was negatively associated with children’s general cognition ($p < 0.05$) at 2 years of age [69], while Hobbs and King (2018) reported similar findings among children who were 5 years old (95% CI $-0.33, -0.44$) [75]. Grineski et al. (2018) reported that food insecurity was negatively correlated with executive function ($p < 0.05$) among children aged 5–9 years old [72]. Contrarily, Alaimo et al. (2001) did not find significant impairment in executive functioning or visuospatial abilities in food-insecure children or teens [73].

A total of 13 studies recruited adult participant samples [70,71,74,76–85]. Among adults, food insecurity has been found to be inversely associated with general cognition [70,76,78–84], executive function [80,82,85], verbal memory [77,80,84], and visuospatial abilities [82]. In some studies, this association was influenced by participant characteristics such as age [74,76], race [83], dementia status [78], or HIV status [71,85]. The study findings from research performed among Puerto Rican adults in the U.S. indicated a significant inverse trend between food security status and general cognitive function ($p = 0.04$), executive functioning ($p = 0.006$), and verbal memory ($p = 0.01$) [74]. The results from a multi-country study among older adults in Europe that measured reports of childhood hunger and cognitive function later in life reported significantly worse verbal memory ($p < 0.04$) outcomes among participants who experienced hunger between ages 0 and

4 when compared with individuals with no past hunger experiences [84]. Additionally, a study of South African adults found that moderate and severe food insecurity were associated with 2.82 (95% CI: 1.65–4.84) and 2.51 (95% CI: 1.63–3.87) times greater odds of impaired general cognition [76].

Primary data analyses were performed in five reviewed studies [71,74,77,82,83], while secondary data analyses were conducted in 12 studies [69,70,72,73,75,76,78–81,84,85]. A relatively diverse demographic has been studied in research investigating the link between food insecurity and cognition, as study samples have included younger to middle-aged Indian adults [77], middle-aged to older Puerto Rican adults [74,82], older Malaysian adults [78], a middle-aged sample of South African adults [76], and middle-aged Burkinabé adults [79]. As detailed in Table 2, the most frequently used measurement items for food security were derived from the United States Department of Agriculture’s Household Food Security Scale [86], while cognitive function was most often examined with the Wechsler Adult Intelligence Scale—Third Edition [87]. Questions from the Household Food Security Scale were used in nine studies [69,70,72,74,75,80–82,85], and items from the Wechsler Adult Intelligence Scale were used in three studies [71,76,80].

A thorough evaluation of the study biases and methodological strengths was conducted (Table 3). To adjust for bias, study researchers used a variety of approaches, including multistage probability design [70], stratified multistage cluster sampling design [76], oversampling of subgroups [69,73], sampling of matched controls [85], and sampling weights [72,73]. Recall bias was present in all studies, given that each was observational by design and included self-reported survey assessments of either food insecurity [69–85] and/or cognitive function [76]. Six studies adjusted for selection bias by obtaining a participant sample that was representative of the greater target population [69,70,72,73,76,81]. Strong measurement validity was determined for nine studies in their evaluations of food insecurity and cognitive function [69–72,74,75,79,80,82,85]. Seven studies had mixed measurement validity due to unreliable or limited food insecurity measures [73,76–78,81,83,84]. Studies were deemed to have mixed validity due to various factors including: severe recall bias derived from self-report measures of early-life childhood food insecurity among older adults who were assumed to have dementia [78], the use of a household food security scale with a homeless study sample [81], and food insecurity measures limited in scope using only one item [73,77,83] or two items [76,84]. Moreover, significant 95% confidence intervals were reported for cognitive function outcomes in 11 studies [70,74–82,84], and all but two studies reported precise statistics [70,82].

Table 2. Measures used across the life course by cognitive domain in studies exploring the mechanisms of food insecurity ^{1,2}.

Citation.	General Cognition:	Executive Functioning: (Working Memory, Cognitive Flexibility, Inhibition, Planning, Reasoning)	Visuospatial Abilities: (Perception, Construction)	Verbal Memory: (Short-Term, Long-Term)
Alaimo et al. (2001) [73]	MMSE ** Serial sevens test * DSST *CI	WISC-R: digit span	WISC-R: block design	
Barnes et al. (2012) [83]		Animal naming task		RAVLT immediate recall RAVLT delayed recall **
Cohn-Schwartz & Weinstein (2020) [84]				
Frith and Loprinzi (2018) [70]				
Gao et al. (2009) [74]	MMSE *	Digit span backward ** Stroop test Letter fluency *	Figure copying test Clock drawing test	Digit span forward Word list learning * Word recognition Word percentage retention *
Grineski et al. (2018) [72]		Numbers reversed test *** 2-step dimensional change card sort test ***		
Hernandez and Jacknowitz (2009) [69]	BSF-R: cognitive scale			
Hobbs and King (2018) [75]	Peabody: PVT-R ** W-J: letter–word *			

Table 2. Cont.

Citation.	General Cognition:	Executive Functioning: (Working Memory, Cognitive Flexibility, Inhibition, Planning, Reasoning)	Visuospatial Abilities: (Perception, Construction)	Verbal Memory: (Short-Term, Long-Term)
Hobkirk et al. (2019) [71]	WAIS-III: digit symbol PASAT-100 NAB digits forward/digits backward test	Stroop test Trail-making test Part B FAS: letter fluency FAS: category fluency	BVMT-R	HVLT
Koyanagi et al. (2019) [76]	MCI ***	WAIS-III: digit span forward and backward ^a Animal naming task ^a		CERAD: word learning ^a CERAD: delayed recall ^a Word list learning: delayed recall *
Mayston et al. (2015) [77]		Animal naming task: memory		
Momtaz et al. (2015) [78]	GMS-AGECAT: Malaysian-adapted **			
Onadja et al. (2013) [79]	LCT * ^{CI}			
Portela-Parra and Leung (2019) [80]	DSST *	AFT *		CERAD: word learning * CERAD: delayed recall
Tan et al. (2020) [85]		Letter–number span task ^a Stroop test ^a Symbol digit modalities test ^a Trail-mMaking test Part B ^a		HVLT ^a COWAT ^a
Tong et al. (2018) [81]	MMSE * ^{CI}	Digit span backward		Digit span forward
Wong et al. (2016) [82]	MMSE * ^{CI}	Stroop test Letter fluency *	Figure copying test *** Clock drawing test	Word list learning Word recognition

¹ AFT: Animal Fluency Test; BSF-R: Bayley Short Form—Research Edition; AUDIT: Alcohol Abuse Disorders Inventory Test; BVMT-R: Brief Visuospatial Memory Test—Revised; CERAD: Consortium to Establish a Registry for Alzheimer’s Disease; COWAT: Controlled Oral Word Association Test; DSST: Digit Symbol Substitution Test; GMS-AGECAT: Geriatric Mental State—Automated Geriatric Examination for Computer-Assisted Taxonomy; HVLT-R: Hopkins Verbal Learning Test; LCT: Leganés Cognitive Test; MCI: Mild Cognitive Impairment; MMSE: Mini Mental State Examination; NAB: Neuropsychological Assessment Battery; NHANES: National Health and Nutrition Examination Survey; PASAT-100: Paced Auditory Serial Addition Task-100; Peabody PVT-R: Peabody Picture Vocabulary Test—Revised; RAVLT: Rey’s Auditory Verbal Learning Test; SHARE: Survey of Health, Ageing, and Retirement in Europe; WAIS-III: Weschler Adult Intelligence Scale; WISC-R: Weschler Intelligence Scale for Children—Revised; W-J Letter–Word: Woodcock–Johnson Test of Achievement Letter–Word Identification Subtest ² * = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$; *^{CI} = significant confidence interval; ^a Statistical results not reported for specific test.

Table 3. Research methodology, study design, biases, measurement validity, and analytical approaches.

Citation	Study Design	Methods to Adjust for Selection Bias	Validity of Measures [+/-]	Recall Bias (Yes/No)	Confidence Intervals (NA/Precise/Imprecise)	Analytical Methods to Adjust for Confounding
Alaimo et al. (2001) [73]	Observational, cross-sectional, secondary data	Oversampling of subgroups Representative sample Sampling weights	+/-	Yes	NA	Main effect linear and logistic models, adjusted for sociodemographics and health outcomes: blood lead concentration, family size, mother’s age at birth, presence of birth complications, low birth weight, prenatal smoke exposure, parental perceptions of child’s health status
Barnes et al. (2012) [83]	Observational, longitudinal, primary data	None	+/-	Yes	NA	Mixed-effect models, adjusted for sociodemographics, medical conditions, geographic region, age, race, sex, years of educational attainment, self-reported myocardial infarction, hypertension, stroke, diabetes, southern vs. other states

Table 3. Cont.

Citation	Study Design	Methods to Adjust for Selection Bias	Validity of Measures [+/-]	Recall Bias (Yes/No)	Confidence Intervals (NA/Precise/Imprecise)	Analytical Methods to Adjust for Confounding
Cohn-Schwartz & Weinstein (2020) [84]	Observational, longitudinal, secondary data	Exclusion of data from participants with a history of brain disease and/or injury	+ / -	Yes	Precise 95% CI = 0.94, 0.99	Multivariable linear regression, adjusted for age; sex; education; body mass index; chronic health conditions; physical activity; smoking cigarettes; depressive symptoms; income; weekly frequency of fruits and vegetables, dairy, fish/chicken/legumes/eggs; previous stress; poor health and financial hardship
Frith and Loprinzi (2018) [70]	Observational, cross-sectional, secondary data	Representative sample Multistage probability	+	Yes	Imprecise 95% CI = -22.3, -0.3	Multivariable linear regression, adjusted for age, race/ethnicity, sex, measured body mass index, c-reactive protein, self-reported smoking status, diabetes status, measured arterial pressure, self-reported physical activity, social support
Gao et al. (2009) [74]	Observational, cross-sectional, primary data	Stratified random sampling	+	Yes	Precise 95% CI = -1.6, -0.19	GLM, adjusted for measured body mass index, measured blood pressure, hypertension, Type 2 diabetes, total homocysteine, age, education, household income, smoking, alcohol intake, poverty status, acculturation, depression
Grineski et al. (2018) [72]	Observational, cross-sectional, secondary Data	Representative sample Sampling weights	+	Yes	NA	Hierarchical linear modeling, adjusted for sociodemographic factors impacting cognitive function: number of parents in the household, US-born parents, household size, teen mother, parental depression, parental health status, and socio-economic status
Hernandez and Jacknowitz (2009) [69]	Observational; Cross-Sectional; Secondary Data	Over-sampling of subgroups Representative sample	+	Yes	NA	Ordinary least squares regression models, including 5 robustness checks; adjusted for child age, child sex, child race/ethnicity, number of times the family eats dinner together, previous food insecurity, birth order, maternal age at birth, maternal education, US-born status, employment status, marital status, income, geographic region, size of city, state-level poverty, percent of people within the state with a bachelor's degrees, state-level food stamp program participation, state-level WIC participation
Hobbs and King (2018) [75]	Observational, cross-sectional, secondary Data	Over-sampling of subgroups with increased risk	+	Yes	Precise 95% CI = -0.33, -0.04	Unconditional quantile regression; difference of means <i>t</i> -test, adjusted for mother's race, low birthweight, maternal education, mother's marital status, mother's employment status, maternal smoking during pregnancy, parental history of substance abuse, US-born status, participation in the Supplemental Nutrition Assistance Program, maternal depression, social support, material hardship, parental stress
Hobkirk et al. (2017) [71]	Observational, cross-sectional, primary data	None	+	Yes	NA	ANCOVA, adjusted for premorbid verbal IQ, hepatitis C infection, income in the past 30 days, any history of homelessness, current health insurance, and HIV+ disease characteristics

Table 3. Cont.

Citation	Study Design	Methods to Adjust for Selection Bias	Validity of Measures [+/-]	Recall Bias (Yes/No)	Confidence Intervals (NA/Precise/Imprecise)	Analytical Methods to Adjust for Confounding
Koyanagi et al. (2019) [76]	Observational, cross-sectional, secondary Data	Representative sample Stratified multistage cluster sampling design	+/-	Yes	Precise 95% CI = 1.63, 3.87	Multivariable logistic regression, adjusted for sex, age, education, income, race, physical activity, smoking use, alcohol use, depression in past 12 months, measured body mass index, stroke, diabetes, hypertension
Mayston et al. (2015) [77]	Observational, cross-sectional, primary data	None	+/-	Yes	Precise 95% CI = 1.05, 1.88	Multivariate logistic regression, adjusted for sex, age, psychological comorbidity; hazardous drinking was adjusted for men only
Montaz et al. (2015) [78]	Observational, cross-sectional, secondary data	Random sampling	+/-	Yes	Precise 95% CI = 1.13, 2.92	Multiple logistic regression, adjusted for age, sex, marital status, educational attainment, ethnicity, and place of residence
Onadja et al. (2013) [79]	Observational, cross-sectional, secondary data	None	+	Yes	Precise 95% CI = 1.06, 3.06	Linear regression, adjusted for age, sex, ethnicity, socioeconomic conditions in childhood, self-rated health during childhood, current socioeconomic status including marital status, body mass index, hypertension
Portela-Parra and Leung (2019) [80]	Observational, cross-sectional, secondary data	None	+	Yes	Precise 95% CI = -0.33, -0.15 95% CI = -0.25, -0.002 95% CI = -0.26, -0.01	Multivariable linear regression, adjusted for age, sex, race/ethnicity, highest education level, marital status, income, smoking status
Tan et al. (2020) [85]	Observational, cross-sectional, secondary data	Recruitment of demographically similar control participants	+	Yes	NA	Multivariable linear regression, adjusted for income, employment status, illicit and non-illicit substance use, body mass index, depression, post-traumatic stress disorder
Tong et al. (2018) [81]	Observational, cross-sectional, secondary data	Random sampling	+/-	Yes	Precise 95% CI = 1.12, 4.35	Logistic regression, adjusted for age, race/ethnicity, employment, residential history, health status, depressive symptoms, smoking status, alcohol use, illicit substance use, social support
Wong et al. (2016) [82]	Observational, longitudinal, primary data	Random sampling	+	Yes	Precise 95% CI = -2.19, -0.20 Imprecise 95% CI = -8.52, -0.85 95% CI = -8.92, -3.43	Logistic regression, adjusted for age, sex, body mass index, education, physical activity score, poverty, acculturation score, smoking status, alcohol use, overall diet quality, presence of hypertension or diabetes, plasma homocysteine concentration, APOE status, depression, relevant baseline cognitive test score, time between assessments

+ = strong validity; - = weak validity; +/- = mixed validity assessment of bias and strength of findings.

4. Discussion

This systematic review explored the association between food insecurity and cognitive function across the life course. It is critical to understand the association between food insecurity and cognitive function to better understand how different forms of adversity are related to cognitive function and to examine the downstream effects of this relationship on other negative health outcomes (e.g., cognitive impairment, obesity, stress). Our results are in accord with Na et al.'s [60] review among adults, while expanding the findings by spanning the human life course through including four studies among children [69,72,73,75] and four adult studies not included in the aforementioned review [71,80,84,85]. The findings in our review also broaden the evidence of a significant association between food insecurity and cognitive function by confirming the findings from other relatively similar

reviews delineating the impact of poor social conditions, such as food insecurity, on the well-being of children [19] and adults [20]. However, it is important to note that many of the studies indicated modest effect sizes, especially when the cognitive function was a continuous outcome.

Differences in general cognitive abilities such as attention, orientation, associative learning, and perceptual speed by food security status were assessed in almost every study of middle- or older adults identified in this review [70,71,74,76,78–83,85]. Tests that assess general cognition may indicate moderate to severe forms of cognitive dysfunction that may affect daily living and quality of life [88–90]. For example, cognitive impairment may affect relationships with others and, in some cases, may impair a person's abilities to live independently [91]. Given that general cognitive faculties are known to decline with age [92,93], the evidence of associations between food insecurity and general cognitive decline is particularly worrisome for older adults, as food insecurity may pose a compounding burden on cognitive health. For those experiencing food insecurity, issues of endogeneity may be at play in the relationships observed in the reviewed studies; however, most studies adjusted for socio-cultural variables often associated with food insecurity such as education, poverty/income, maternal age at birth, or race/ethnicity.

While cognitive function among middle-aged and older adults with food insecurity has been discussed previously [60], our review yields novel study findings indicating significant inverse associations between food insecurity and general cognitive function in studies of toddlers and young children [69,75]. Impaired cognitive development in children is associated with behavioral issues such as irritability, impatience, and distractibility [94]. Related evidence has established links between food insecurity and behavioral issues in children (e.g., aggression, anxiety, hyperactivity) [95–98], thus raising the question of whether the impairment of cognitive development is a mediating factor in such associations. Only one study, to our knowledge, provided credible evidence of an association between food insecurity and impaired cognitive development in children [75], thus highlighting a need for further research in order to better understand how food insecurity impacts human development in children.

Executive function, another commonly explored aspect of cognitive function, involves higher-order cognitive processes allowing individuals to plan, regulate behavior, and achieve goals [99]. Related research has shown that food insecurity is associated with aspects of children's academic performance [12,96], and executive functions such as working memory abilities are known predictors of academic performance [100]. The impairment of working memory may play a role in the association between food insecurity and academic outcomes, although no research has directly explored this possibility. However, it has been proposed that the association between food insecurity and impaired executive functioning in both children and adults may result from the effects of unhealthy stress on the prefrontal cortex [101,102], an essential brain region for carrying out executive functions [103]. Future research is needed to examine the relative effects of factors associated with cognitive functioning such as stress and food insecurity.

An unexpected finding in our review is that moderate food insecurity may have a greater impact on cognitive function compared with greater levels of food insecurity [76]. This observation is similar to results from previous research, where acute food insecurity had a greater impact on behavioral outcomes among children than chronic food insecurity [69,72], which might be explained in terms of the impact of stress on those with acute versus chronic food insecurity. Individuals suffering from chronic food insecurity might develop coping strategies for dealing with longer-term food insecurity, while those with acute food insecurity experiences may be less resilient due their volatile food security status. Acute food insecurity could involve less predictable circumstances than chronic food insecurity, and it is possible for such unpredictable circumstances to induce greater stress compared with more familiar situations [104]. Future research is needed to confirm how chronic and acute food insecurity are associated with cognitive functioning. However, it is unknown how altering food insecurity alone may impact cognitive function. Perhaps

it is only when we are able to address the multifactorial root causes of social determinants of health that impact chronic and acute stress such as food insecurity, we will be able to see improvements in cognitive function for vulnerable populations.

Given that most studies included in the review were secondary analyses of large, representative datasets, studies were able to consider several confounding variables in their analyses related to both food insecurity and cognitive function, most consistently sociodemographics, depression, health behaviors (e.g., smoking), and body mass index. However, the inclusion of specific confounders was not consistent, nor were they exhaustive of factors that are related for to food insecurity. For example, research has indicated that adverse childhood experiences are related to food insecurity [105,106] and, independently, cognitive function [107,108]. Other research has linked structural racism independently from food insecurity [109,110] and cognitive function [111]. Importantly, food insecurity may be a proxy for other individual and societal factors not assessed in the studies included in this review. Research is needed to explore the relative impact of food insecurity and other forms of adversity on cognitive function. Further, all studies were observational. While some studies were longitudinal, no studies were able to address all aspects of causal inference. It is possible that reverse causality is at play, where cognitive function impacts the ability to consistently access food; however, all 17 studies examined in the current review assessed their hypothesis in one direction: food insecurity as the independent variable and the cognitive outcome(s) as the dependent variable. Further research is needed to examine the possible causal pathway involved in the association between food insecurity and various types of cognitive function.

Strengths and Limitations

This systematic review has certain strengths and limitations that should be considered when interpreting the findings. One strength involved our assessment of bias, which included select items from the Preliminary Tool for Risk of Bias in Exposure Studies [65], Q-Coh [66], and tools for grading the strength and quality of a body of evidence [67,68]. These tools permitted the investigators to perform comprehensive assessments of biases within the included studies to determine the validity and reliability of the study findings. This study included every age group across the life course, as this approach permitted the investigators to compile all findings that were relevant to the association between food insecurity and cognitive function, and to proceed to establish a comprehensive understanding of what is already known about this relationship while subsequently articulating the knowledge gaps that still need to be addressed by research. However, because such a variety of measures of cognitive function were examined, a meta-analysis was not possible. A limitation of this study was the inclusion of studies with participants whose health and socioeconomic status confounded their measured food security and cognitive functioning (e.g., older adults with dementia, homeless individuals). However, these studies were included to better understand food insecurity experiences among people living with diverse conditions. An additional limitation is that most studies in our review using secondary data for statistical analyses, which poses study design restrictions for researchers concerning participant sampling, construct measure selection, and data collection approaches. Furthermore, the generalizability of the findings from study to study in this review is uncertain due to the multitude of different measures used to examine the same constructs.

5. Conclusions

The findings from this review indicate that food insecurity status correlates with poorer cognitive function across the life course. Our review corroborates the findings from a recently published review detailing an inverse relationship between food insecurity and both executive functioning and verbal memory among middle-aged and older adults. Our expansive life course review provides critical evidence detailing how children with food insecurity may suffer from delayed cognitive development, which could negatively impact academic performance while increasing the risk of poorer health outcomes later in life.

There is a need for further research exploring the associations between food insecurity and cognitive function among certain populations (e.g., adolescents, young adults, college students). Research is also needed that objectively measures brain structure and function to more fully understand the ramifications of food insecurity experiences. Overall, the evidence from this review highlights a present and critical need for nutrition and public health interventions aimed at preventing food insecurity and cognitive decline.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/ijtm1030015/s1>. Table S1: Comprehensive list of search terms to identify literature assessing the relationship between food insecurity and cognitive function.

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