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Food Insecurity Is Associated with Subsequent Cognitive Decline in the Boston Puerto Rican Health Study[1–3]

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Abstract

Background: Living with hunger and fear of not having enough food is a growing worldwide concern. In our previous cross-sectional study, we found that food insecurity was associated with poor cognitive function, but the direction of this relation remains unclear.

Objective: We investigated whether food insecurity is associated with subsequent cognitive decline.

Methods: This was a longitudinal study of 597 participants aged 40–75 y from the Boston Puerto Rican Health Study cohort, with a Mini-Mental State Examination score of ≥24 at baseline. Food security was assessed at baseline with the US Household Food Security Scale. Participants completed cognitive batteries, which included 7 cognitive tests, twice—at baseline and again at a 2-y follow-up. The primary outcome was the change in global cognitive function over 2 y. Multiple linear regression was used to obtain adjusted mean differences and 95% CIs in cognitive decline across baseline food security status.

Results: Food insecurity at baseline was associated with a 2-y decline in global cognitive function (*P*-trend = 0.03) after adjusting for relevant potential confounders, including age, sex, baseline cognitive score, body mass index, education, poverty, acculturation score, depression score, smoking status, use of alcohol, physical activity score, presence of diabetes and hypertension, apolipoprotein E status, plasma homocysteine, healthy eating index, and time between baseline and follow-up measures. Compared with the food-secure group, the decline in the very low food security group was greater [mean difference: −0.26 (95% CI: −0.41, −0.10)]. Baseline food insecurity was significantly associated with a faster decline in executive function (*P*-trend = 0.02) but not memory function (*P*-trend = 0.66).

Conclusions: Food insecurity was associated with faster cognitive decline in this cohort of Puerto Rican adults. Our study emphasizes the importance of developing interventions for food insecurity that take into account the impact of food insecurity on cognition. *J Nutr* 2016;146:1740–5.

Keywords: cognitive decline, dementia, epidemiology, public health, nutrition

Introduction

Food security is defined as having access to nutritionally adequate and safe foods at all times to sustain a healthy lifestyle and requires adequate food availability, accessibility, and utilization (1). Ensuring food security is a national and global priority with economic and sociopolitical implications. According to the USDA, there were ~14.5 million households in the United States in 2012 who were food insecure at some point during the year (2). The USDA also estimated that there were >700 million food-insecure people in 76 low- or middle-income countries in 2012–2013 (3). The prevalence of food insecurity highlights the importance of understanding its potential unfavorable consequences.

In 2009, we demonstrated that food insecurity was prevalent (12.1%) in a cohort of Puerto Rican adults living in the greater Boston area enrolled in the Boston Puerto Rican Health Study (4). This cohort was an underprivileged aging population with a high prevalence of very low food insecurity and mild cognitive impairment (4). Food insecurity, particularly very low food security, was associated with poorer cognitive test performance, including lower scores on the Mini-Mental State Examination

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(MMSE), word list learning, percentage retention, letter fluency, and digit span backward tests (4). However, because this was a cross-sectional study, the direction of the relation between food insecurity and cognitive decline was unclear: the food-insecure groups could be more likely to become cognitively deficient, but those with cognitive deficits could be more likely to become food insecure. Two-year follow-up data are now available for participants in this same cohort, allowing us to investigate the temporal relation between food insecurity and cognitive decline. We hypothesized that food insecurity would be associated with a faster rate of cognitive decline.

Methods

Participants. This study was approved by the Tufts Medical Center institutional review board, and participants provided written informed consent before study participation. The selection of study participants, measurement of food security status and cognition, and relevant covariates have been previously described (4). Briefly, in the Boston Puerto Rican Health Study cohort, 1499 Puerto Rican participants aged 45–75 y living in the greater Boston area completed the baseline cognitive exam, and 1207 (80.5%) participants completed the cognitive exam at the 2-y follow-up. At baseline and follow-up, participants were interviewed at home by bilingual interviewers in Spanish or English. Those who were lost to follow-up were more likely to be women (37.8% compared with 27.6%; $P = 0.007$) but had a similar age, MMSE score, and proportion of food insecurity and poverty ($P > 0.10$ for all) as those who completed the 2-y follow-up interview.

Because we aimed to test the hypothesis that food security status was associated with subsequent cognitive decline over 2 y of follow-up, we further excluded 610 (50.5%) individuals with a baseline MMSE score of <24 because of reverse causality concerns.

Assessment of food security status. Food security status was assessed with 10 questions in the standard US Household Food Security Survey module related to circumstances in the year before survey completion (5). Participants with <3 affirmative responses were considered food secure, those with 3–5 affirmative responses were considered food insecure, and those with ≥6 positive responses were considered very food insecure as recommended by the USDA (4).

Assessment of cognitive function. The participants underwent a battery of cognitive tests in either Spanish (98% of participants) or English by a trained research assistant (4). The same cognitive battery was administered at baseline and at a 2-y follow-up. Participants who were unable to read aloud sentences in large print or hear or follow one-step commands were excluded. Seven cognitive tests were conducted: *1*) the MMSE (6) to assess general cognitive function; *2*) 16-word list learning (7) to assess verbal memory, testing word list learning (sum of words recalled over *5* trials), recognition, and percentage retention (calculated by dividing the number of words recalled after delay by the number of correct responses on the fifth learning trial); *3*) digit span forward and backward (7) to assess attention and working memory; *4*) the Stroop test (7); *5*) verbal fluency (7) (to name as many words that start with a given letter); *6*) clock drawing (8); and *7*) figure copying (9) to assess executive function (4).

We focused our analyses on measures of general cognitive decline over time. Calculating a global cognitive decline score has been described previously (10). Briefly, in primary analyses, we calculated a global cognitive decline score by averaging the z scores for changes in each of the following cognitive scores: MMSE, word list learning, recognition, percentage retention, Stroop, letter fluency, digit span forward and backward, clock drawing, and weighted figure copying. The global score was only calculated for participants who completed all the component tests at baseline and a 2-y follow-up ($n = 544$). The global cognitive score at baseline was also used as a covariate that was included in the models. To understand the key aspects of cognitive decline affected by food insecurity, we used principal component analysis (PCA) to identify 2 major cognitive function factors (executive function and memory) as detailed previously (10).

We then examined the association between baseline food security status and changes in executive function and memory (**Supplemental Table 1**) and each individual cognitive assessment test score in secondary analyses. PCA with varimax rotation was used as a data reduction technique to derive composite scores for separate cognitive domains. PCA was performed on baseline cognitive data, resulting in 2 principal components with eigenvalues >1. Based on loadings for individual baseline test scores on the 2 principal components, the individual components were designated as measuring the cognitive domains of executive function and memory. By definition, each PCA-derived composite score had a mean of 0 and SD of 1. Composite scores were also computed for the 2-y follow-up testing data with the use of the means, SDs, and scoring coefficients from the baseline PCA. Difference scores for baseline minus follow-up were calculated for each domain, and descriptive statistics were obtained for these difference scores. For each cognitive domain, "decline" was defined by a drop in score of ≥1 SD from the group mean difference score (11, 12).

Assessment of potential covariates. Information on age, years of education, household income, marital status, employment status, household income, family size, acculturation, migration history, smoking status, and alcohol intake was collected by a questionnaire. Symptoms of depression were assessed via the Center for Epidemiologic Studies Depression Scale, which has been widely used in previous epidemiologic studies conducted in Hispanic populations (13, 14). Poverty status was computed with the use of the poverty guidelines released each year by the US Department of Health and Human Services: a subject's total annual household income was compared to the poverty guideline for the subject's family size and for the year of interview (15). The subject was considered to be below the poverty line if the total household income was less than this guideline (15).

Body weight and height were measured by trained fieldworkers during the interview, and BMI (in kg/m^2) was calculated. We measured blood pressure at 3 time points during the home interview. Hypertension was defined as mean systolic blood pressure ≥140 mm Hg and/or mean diastolic blood pressure ≥90 mm Hg. Subjects were identified as having type 2 diabetes if fasting plasma glucose was >7.0 mmol/L or if they reported taking medications for diabetes (insulin or oral medicines) (16). Fasting (12-h) blood samples were drawn in the home by a certified phlebotomist on the day after the home interview, and total homocysteine in plasma was measured by adapting a previously described method (17). The coefficient of variation for this assay in our laboratory was 6.0%. The *APOE* genotype was assessed with the TaqMan single-nucleotide polymorphism genotyping assay (Applied Biosystems) with a success rate of 95%.

Statistical analyses. Statistical analyses were performed with SAS version 9.1 (SAS Institute). Participants were categorized according to their baseline food security status (secure, low secure, and very low secure), with $\alpha = 0.05$. Means were compared with the use of the general linear models procedure in SAS. Logistic regression was used to test differences in prevalence across categories. We used multiple linear regression models to obtain adjusted mean differences and 95% CIs in cognitive decline across baseline food security status. Linear trends were tested for significance with the use of the original food security score as a continuous variable. As described previously, the primary outcome was global cognitive decline. In secondary analyses, we explored the association between food security status and change of each of individual cognitive function test scores. We also used multiple logistic regressions to estimate ORs of decline in executive and memory function (defined as a decline of ≥1 SD over the 2 y from participants' baseline scores), respectively, and adjusted for potential confounders (11, 12).

Analyses were adjusted for age, sex, BMI, education, physical activity score, poverty, acculturation score, smoking status, alcohol use, overall diet quality [as assessed by the 2005 healthy eating index (18)], presence of hypertension or diabetes, plasma homocysteine concentration (μmol/L), *APOE* status (presence of *APOE2* allele or *APOE4* allele), depression, relevant baseline cognitive test score, and time between baseline and the second interview. The assessment of these covariates has been previously described (4).

By including multiplicative terms in the regression models, we examined the interaction between the baseline food security status and known risk factors for cognitive decline, including age, sex, current smoking status, obesity, diet quality score, and poverty status (4).

Among 698 participants with an MMSE score of ≥24 at baseline, 101 (14.5%) did not complete the second cognitive test. We used multiple imputation for these missing values based on a fully conditional method that has previously been described (19). We generated 5 complete data sets and examined the association between food security status and cognitive decline.

Results

In this sample of 597 cognitively intact Puerto Rican adults, 9.5% reported food insecurity during the past 12 mo (**Table 1**). Food insecurity was significantly associated with a younger age ($P < 0.05$), poverty ($P < 0.01$), current smoking ($P < 0.05$), lower healthy eating index ($P < 0.01$), and depressive symptomatology ($P < 0.01$).

Global cognitive function scores at the 2-y follow-up compared to baseline were significantly worse in the food-insecure groups, as shown by the significantly more negative mean difference in cognitive function (**Table 2**). This significant association was seen after adjusting for age, sex, and baseline cognitive function in model 1 and age, sex, baseline cognitive score, BMI, education, poverty, acculturation score, smoking status, use of alcohol, physical activity score, diabetes, hypertension, *APOE* status, plasma homocysteine, and healthy eating index in model 2 (P-trend = 0.03). Specifically, we found that baseline food insecurity was significantly associated with a faster decline in executive function (P-trend = 0.02) but not memory function (P-trend = 0.66) (Table 2). Food insecurity was consistently associated with substantial changes in executive function but not memory; the adjusted ORs in comparing very low secure and secure groups were 5.07 (95% CI: 1.52, 16.9; P-trend = 0.01) for executive function and 0.68 (95% CI: 0.11, 4.08; P-trend = 0.23) for memory.

We also examined each individual cognitive test and found that individuals with food insecurity had a faster decline in figure copying scores (P-trend < 0.0001), letter fluency (P-trend = 0.04), and MMSE scores (P-trend = 0.05) over the 2 y of follow-up (**Table 3**). The associations between food insecurity and decline in other individual tests were not significant.

Sensitivity tests with the use of multiple imputation of the missing data for cognitive tests at the second visit showed no material differences in the results (**Supplemental Table 2**). To examine whether the association between food security and global cognitive function could be explained by the figure copying test, we conducted another sensitivity test by removing the figure copying test from the global score. The very low secure group still experienced a faster decline in cognitive score relative to the secure group (adjusted mean difference = 0.18; P = 0.02). Further adjustment for migration history (place of birth and years in the United States), marital status, plasma vitamin B concentrations, and employment status did not materially change the significant association between food security and cognitive score decline (data not shown).

We further examined whether the observed association between food security status and global cognitive decline was modified by age, sex, BMI, baseline MMSE score, smoking status, diet quality score, and poverty status. The analysis revealed that the association between lower food security and a faster cognitive score decline was more pronounced in participants with better baseline cognitive function (MMSE score of ≥27; adjusted mean difference = −0.38; P-trend = 0.003; P-interaction = 0.03) or those below the poverty line (adjusted mean difference = −0.42; P-trend = 0.03; P-interaction = 0.09) relative to other participants. There were no significant interactions between food security and other factors.

TABLE 1 Characteristics of Boston Puerto Rican Health Study participants according to baseline food security status[1]

		Food insecure	
	Food secure	Low food security	Very low food security
n	540	33	24
Age, y	55.9 ± 0.2	55.3 ± 1.3	52.3 ± 1.5[2]
Female, %	68.3	51.5	70.8
BMI, kg/m^2	31.9 ± 0.3	31.7 ± 1.3	29.0 ± 1.3
Physical activity score	32.4 ± 0.2	31.5 ± 0.9	30.7 ± 1.0
Education <5th grade, %	11.1	12.1	8.3
Poverty, %	42.3	58.1	69.6[3]
Acculturation score	31.4 ± 0.95	25.8 ± 3.8	41.2 ± 4.5
Born in Puerto Rico, %	94.6	93.9	95.8
Years in United States	34.8	34.6	37.5
Past smoker, %	32.0	33.3	4.2[3]
Current smoker, %	24.1	30.3	58.3[2]
Past drinker, %	29.6	33.3	33.3
Current drinker, %	46.2	45.5	54.2
Presence of diabetes, %	37.2	25.0	22.7
Presence of hypertension, %	68.2	65.6	66.7
Plasma homocysteine, μmol/L	8.3 ± 1.0	8.2 ± 1.0	8.7 ± 1.1
Plasma vitamin B-12, pmol/L	566 ± 12	509 ± 50	558 ± 61
Presence of *APOE2*, %	12.2	13.6	30.0
Presence of *APOE4*, %	19.9	18.8	22.7
Healthy eating index	72.1 ± 0.4	71.4 ± 1.7	63.8 ± 2.0[3]
MMSE score	26.1 ± 0.07	25.8 ± 0.3	26.4 ± 0.3
Global cognitive score	0.02 ± 0.02	−0.12 ± 0.09	−0.02 ± 0.10
CES-D score	17.8 ± 0.5	26.3 ± 2.3[3]	26.1 ± 2.6[3]

[1] Values are means ± SEs adjusted for age and sex, unless otherwise indicated. Means were compared with the use of the general linear models procedure in SAS version 9.1. Logistic regression was used to test differences in prevalence across categories. CES-D, Center for Epidemiologic Studies Depression Scale; MMSE, Mini-Mental State Examination.
[2] $P < 0.05$ relative to participants who were food secure.
[3] $P < 0.01$ relative to participants who were food secure.

Discussion

In this cohort of Puerto Rican adults in the greater Boston area, food insecurity was associated with faster cognitive decline, particularly global cognitive decline. Investigating the downstream effects of food insecurity is a pressing issue both nationally and globally given the predicted worsening of food insecurity in the near future. The International Food Security Assessment for 2013–2023 projects an estimated increase in the number of food-insecure individuals of 23% or up to 868 million (3). There is also expected to be a 28% projected increase in the distribution gap—the amount of food required to meet nutritional targets (3).

In a recent study (20), poverty was linked to worsened cognitive performance and capacity, and the authors hypothesized that scarcity tended to consume mental resources. Briefly, in their first experiment, poor subjects had worse cognitive performance when induced with thoughts about difficult financial situations (20). In their second experiment, farmers had

TABLE 2 Mean difference (95% CI) in cognitive decline during the 2-y follow-up of Boston Puerto Rican Health Study participants according to baseline food security status

	Food secure (n = 540)	Food insecure		*P*-trend
		Low security (n = 33)	Very low security (n = 24)	
Global cognitive score				
Model 1[2]	0 (ref[1])	−0.02 (−0.14, 0.10)	−0.19 (−0.33, −0.04)	0.02
Model 2[3]	0 (ref)	0.04 (−0.09, 0.17)	−0.26 (−0.41, −0.10)	0.03
Major cognitive function factors[3]				
Executive function	0 (ref)	0.09 (−0.15, 0.34)	−0.47 (−0.77, −0.18)	0.02
Memory	0 (ref)	−0.03 (−0.34, 0.28)	−0.08 (−0.46, 0.30)	0.66

[1] ref, reference.
[2] Adjusted for age, sex, and baseline global cognitive score.
[3] Adjusted for age, sex, baseline relevant cognitive score, BMI (in kg/m^2), education, poverty, acculturation score, depression score, smoking status, use of alcohol, physical activity score, presence of diabetes and hypertension, *APOE* status, plasma homocysteine (μmol/L), healthy eating index, and time between baseline and follow-up measures.

worse cognitive performance before rather than after harvests when they were poorer (20). Likewise, we found that the association between food insecurity and cognitive decline was more pronounced for people living in poverty. Overall, these findings suggest that people living in poverty could be more vulnerable to cognitive decline. Food security status could also be consistently associated with cognitive development in children. One study (21) showed that food insufficiency was associated with lower math scores and a higher likelihood of repeating a grade, having seen a psychologist, or having difficulty getting along with others. Severe food insecurity was also associated with increased odds of neurological disorders, such as seizures, movement abnormalities, carpal tunnel syndrome, vision problems, and spinal pain (22).

How, then, is food insecurity associated with subsequent cognitive decline? Although our study could not confirm the mechanisms underlying the relation between food insecurity and cognitive decline, there may be several possible explanations. First, food insecurity may be linked to cognitive decline via stress. Allostatic load is understood as the "wear and tear of stress" that stems from a combination of genetics, developmental history, experiences, and individual habits, including diet (23). Physiological changes in stress and allostatic load can help with short-term adaptation but promote the development of disease in the long term (23). Second, food insecurity may also be related to subsequent cognitive decline via poor food quality because the Boston Puerto Rican Health Study participants' diets had relatively poor diversity and micronutrient content (24). Past studies support the association between healthy eating and improved cognition; e.g., the healthy Mediterranean diet was associated with a decreased risk of developing Alzheimer disease, and healthy eating patterns were associated with higher MMSE scores (25, 26). Similar positive associations between dietary pattern and cognitive function were also observed in this Puerto Rican population (18).

Food insecurity is associated with other psychosocial factors and health issues. In a study of women in California (27), factors associated with food insecurity included Hispanics or blacks, less education, unmarried status, younger age, speaking Spanish, and less time spent in the United States. Food insecurity was also associated with poorer general, physical, and mental health (27). In a study on US-Mexico border farmworkers, those with food insecurity were more likely to have depression, anxiety, and learning disorders than those with more food security (28). Food insecurity and stressful life events were also associated with depression, anxiety, and posttraumatic stress disorder in a study in Ethiopia (29). Although we adjusted for most of these potential confounders (or intermediate factors) in our model of food insecurity and cognition, we could not completely rule out the existence of residual confounding.

TABLE 3 Mean difference (95% CI) in decline in individual cognitive test scores during the 2-y follow-up of Boston Puerto Rican Health Study participants according to baseline food security status[1]

Individual cognitive test[2]	Food secure	Food insecure		*P*-trend
		Low security	Very low security	
MMSE	0 (ref)	−0.07 (−0.92, 0.79)	−1.20 (−2.19, −0.20)	0.05
Word list learning	0 (ref)	−2.24 (−6.01, 1.34)	1.16 (−3.01, 5.44)	0.61
Recognition	0 (ref)	1.03 (−0.65, 2.70)	−0.14 (−3.29, 0.61)	0.58
Stroop	0 (ref)	−0.43 (−3.15, 4.01)	−0.45 (−3.72, 4.61)	0.80
Letter fluency	0 (ref)	−0.88 (−4.18, 2.42)	−4.67 (−8.52, −0.85)	0.04
Digit span				
Forward	0 (ref)	0.08 (−0.48, 0.64)	−0.43 (−1.10, 0.24)	0.52
Backward	0 (ref)	0.39 (−0.13, 0.91)	−0.09 (−0.69, 0.51)	0.50
Clock drawing	0 (ref)	−0.08 (−0.39, 0.18)	−0.17 (−0.39, 0.29)	0.81
Figure copying	0 (ref)	−1.09 (−3.45, 1.26)	−6.18 (−8.92, −3.43)	<0.0001

[1] MMSE, Mini-Mental State Examination; ref, reference
[2] Adjusted for age, sex, baseline relevant cognitive score, BMI (in kg/m^2), education, poverty, acculturation score, smoking status, use of alcohol, physical activity score, depression score, presence of diabetes and hypertension, *APOE* status, plasma homocysteine (μmol/L), healthy eating index, and time between baseline and follow-up measures.

We found that food insecurity was associated with a decline in executive function, which is especially concerning because this domain is involved with overarching cognitive processes such as reasoning and planning. We speculate that this may be caused by the vulnerability of the prefrontal cortex—a brain region that plays a key role in executive function—to detrimental effects of stress (30, 31). Exposure to stress can impair prefrontal cortex function because of the high concentrations of dopamine and glucocorticoids that are released, and chronic stress results in architectural changes in prefrontal dendrites (30, 31). Interestingly, food insecurity was not associated with a decline in memory, which is a key feature of Alzheimer disease, suggesting that cognitive decline associated with food insecurity may have other pathological mechanisms.

There were several limitations in this study. First, although a temporal association was demonstrated between food insecurity and subsequent cognitive decline, causation could not be established because of the observational nature of the study. Although we controlled for many clinical and demographic variables, there may be other diet-, stress-, or psychosocial-related variables that could mediate the relation between food insecurity and cognition or confound the analysis. Second, we assessed changes between 2 time points, separated by 2 y, so were unable to assess cognitive decline beyond 2 y. More time points would have also helped confirm a trend over time. This is also important for exploring whether the observed association between food security and cognitive decline is modified by psychosocial factors or diet quality, which would help us to understand potential underlying biological mechanisms. Third, this study focused on a specific population of Puerto Rican adults in Boston, so results may not be necessarily generalizable to other populations. Fourth, although determining food security status depended on participant recall, which could introduce recall bias, we used the validated instrument that the USDA also uses to help determine food security status. Fifth, food insecurity could be a marker for low socioeconomic status, but analyses controlled for several socioeconomic variables, including education, poverty, and acculturation. Finally, there were relatively fewer participants with low or very low food security status, which could affect the power of the study, but we nevertheless found significant associations between food insecurity and cognitive decline.

Given the global prevalence of food insecurity, the association between food insecurity and faster cognitive decline emphasizes the importance of interventions to improve food security. Interventions are especially crucial because food security is a modifiable factor, and inequality in food security is a major social justice issue. Food insecurity—whether from low income or food scarcity—creates power differentials, favoring those who control food supply (32), and the impact of food insecurity of cognition may further exacerbate these differentials. Policymakers should develop streamlined and simple processes to avoid cognitively taxing those in poverty (20). Given the link between food insecurity and faster cognitive decline, we recommend that future interventions for food insecurity account for potential limitations in cognition—especially executive function—in the target population.

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JCW, KLT, and XG designed the research; TS and KLT provided the essential materials; Y-GL and XG analyzed the data; JCW and XG wrote the paper; TS, PW, Y-GL, and KLT critically revised the manuscript for important intellectual content; and XG had primary responsibility for final content. All authors read and approved the final manuscript.

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