Early-life food deprivation and cognitive performance among old-age Europeans

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Abstract

Background: Early-life adversity, including food deprivation, has been linked with late-life cognitive function. Our aim was to explore the association between history of hunger, age at hunger and its duration with cognitive performance and decline among old-age Europeans.

Methods: Our sample included dementia-free individuals aged ≥65 years who participated in waves 3 and 4 of the Survey of Health, Ageing and Retirement in Europe (SHARE). Information on periods of hunger during life-course was gathered in wave 3 (2009;SHARELIFE). Cognitive performance was assessed using tests of memory, verbal fluency and numeracy in waves 4 (2011) and 5 (2013). Regression models were used to assess the relationship between exposure to hunger at different ages and hunger duration with cognitive performance and decline while adjusting for age, sex, education, life-style and health factors.

Results: Among a sample of 2,131 individuals (mean age=76.2; 50% women), exposure to hunger during ages 0-4 years was associated with poorer immediate and delayed recall, fluency and impaired numeracy factors (B±SE=-0.58±0.12; p<0.001; B±SE=-0.74±0.13; p<0.001, B±SE)=-1.60±0.42;p<0.001 and OR [95% CI]=0.57 [0.42-0.79], respectively). These results attenuated after controlling for hunger duration but remained significant for delayed recall. Hunger at ages 12-18 years was associated with better immediate recall, delayed recall and fluency (B±SE=0.38±0.15; p=0.010; B±SE=0.37±0.17; p=0.026, B±SE=1.57±0.53; p=0.003, respectively). The associations of hunger with cognitive decline were similar but less robust.

Conclusions: Our findings suggest that severe nutritional deprivation in early childhood may be associated with poor cognitive function while food deprivation in later childhood and adolescence may be protective.

Keywords: cognitive performance, food deprivation, childhood, old-age, longitudinal.

1. Introduction

With aging, cognitive function varies considerably between individuals. While some older adults have atypically large cognitive decline, others deviate by having strikingly high-performance levels long into advanced age [1,2]. It is thought that the rate of cognitive decline in late-life is determined by a complex interplay between various risk and protective factors which exert their effect on the brain at different times during the life course beginning in gestation [3]. Specifically, the early-life period is considered a sensitive time window in which the brain shows pronounced growth and development, and thus environmental factors can exert substantial and lasting effects on its structure and function [4,5].

The importance of nutritional status in early stages of life to brain health in old age may be indicated by utilizing information on the cognitive consequences of food deprivation. In a recent meta-analysis, individuals exposed to food deficiency during childhood had approximately 2-fold increase in risk for cognitive impairment compared to those who did not experience food deprivation, however this estimate was based on two studies only [6]. In line with these findings, severe food deprivation during the Chinese famine in early life was associated with poorer cognitive performance [7,8] and with a greater cognitive decline [9]. However, no significant associations were found between exposure to the Chinese famine and measures of global cognition or incident dementia [8,9], and the authors concluded that the consequences of the Chinese famine were not severe enough to be linked with dementia risk [9]. Furthermore, an unexpected protective role of food deprivation during childhood in relation to late-life brain health has been demonstrated among African-Americans who participated in the Chicago Health and Aging Project [10].

The inconsistencies in previous findings may reflect, at least partly, the heterogeneity in periods during the life-course in which food deprivation has occurred. Studies assessing food deprivation in specific periods during the life-course, and particularly during early adulthood are sparse, and findings are conflicting. In a study conducted in Ghana, famine was associated with cognitive development only in those exposed to it between the ages of 0 to 2 years but not in older ages [11]. Nevertheless, it has also been shown that only those exposed to the Chinese famine at ages 7-9 years showed poorer performance on the Montreal Cognitive Assessment while no association with famine during the younger or older age groups was found [9].

In addition to assessment of specific time periods of food deprivation in early-life, another factor that can contribute to late-life brain health is the length of food deprivation period, which to our knowledge, was not accounted for in previous literature. Thus, in the current study we sought to assess the relationship of food deprivation in different stages of early life and its duration with cognitive performance and decline among elderly individuals who participated in the Survey of Health, Ageing, and Retirement in Europe (SHARE) [12].

2. Methods

2.1 Study sample

SHARE is a multidisciplinary cross-national, longitudinal survey which collects information on nationally representative samples of adults in Europe. The survey participants are community-dwelling individuals aged 50 years and older and their spouses of any age [12]. Interviews are conducted in the respondents' house by trained

interviewers, using a computer-assisted personal interviewing program (CAPI), following the participants' informed consent.

The current analysis focused on individuals who participated in the third survey wave, which collected retrospective data (2008/9), as well as in the following Wave 4 (2011). In addition, we restricted our sample to include only those aged 65 years and above in Wave 4 (N=9744), because a steeper cognitive decline has been observed starting from this age [13]. We excluded 204 participants who reported being diagnosed with a stroke, Parkinson's disease or Alzheimer's disease in wave 4, resulting in an initial sample of 9726. Of this sample, 11% (1065) experienced some periods of hunger during their lives. The hunger group was matched with a control group that did not experience hunger using propensity scores based on age, gender and education via the Coarsened Exact Matching method [14]. The matched control sample included 1066 respondents who did no report food deprivation, but who were similar in age, gender and education to those who reported experiencing periods of hunger. Thus, the main analytical sample for the current analysis included 2131 participants.

2.2 Measurements

The cognitive evaluation included four cognitive tests. Immediate and delayed episodic memory was assessed using the modified version of Rey's Auditory Verbal Learning Test—RAVLT [15] which evaluates short-term verbal learning and memory. In SHARE, the interviewer reads out a list of 10 words, after which the respondent is asked to recall as many of them as s/he can. The test is then repeated after 5–10 minutes. Numeracy was measured using the Serial Sevens test, in which respondents are asked to count down from 100 by sevens, for four times. The test measures concentration and basic calculation skills [16]. Respondents received one point for each correct answer [17]. The numeracy variable therefore ranges from 0 to 5, however due to a high rate

of correct responses (mean = 4.2), its scores were divided into two categories: 0 = at least one mistake; 1 = the entire test answered correctly. Lastly, executive function and language ability were assessed by a verbal fluency test, in which the participants were required to state the names of as many animals as they could in a 1-minute period [18]. Due to outliers in a small number of cases, scores above 45 were re-coded as 45.

Information on periods of hunger was collected in wave 3 of SHARE (2008/9), which focused on gathering retrospective information on respondents' life course. Respondents were asked: "(Looking back on your life,) was there a period during which you suffered from hunger?" If their answer was positive, they were asked to indicate the year in which this period of hunger started and the year in which it stopped. We then calculated the age of respondents when the hunger period began and divided them into four age groups: 0-4 years; 5-11 years; 12-18 years and 19+ years. We added to this variable another group of participants who did not experience hunger, which was used as a reference category in the regression analyses. We used the number of hunger years as an additional predictor.

The study included socio-demographic and health covariates [19]. These were: age, sex, education level (low and secondary\high educational attainment) [20], body mass index (BMI) based on self-reported height and weight, number of chronic conditions, physical activity (yes\no), currently smoking cigarettes (yes\no), depressive symptoms [21], income (adjusted for household size and divided to tertiles within each country), frequency of weekly consumption of fruit or vegetables, dairy products, fish or chicken and legumes or eggs. Information on occurrences of earlier periods of stress, poor health and financial hardship was also collected.

2.3. Statistical analysis

Data analysis was conducted using STATA (version 15). Linear regression models evaluated the associations of history of hunger - its age periods and duration - with cognitive performance on the immediate and delayed word-list recall and the fluency tests. The numeracy test was a dichotomous variable, therefore logistic regression models were conducted to assess its relationship with hunger parameters in earlier life. Additionally, we assessed the relationship of hunger periods with change in cognitive performance between wave 4 and 5, by assessing the relationship of the hunger variables with cognitive performance at wave 5 while controlling for cognitive variables at baseline (wave 4). For each outcome in the regression analyses, four models were examined: the first entered age of hunger, while adjusting for age, sex and education. The second model added the remaining covariates. The third model added years of hunger, without age of hunger, while controlling for all the covariates. The fourth model included age of hunger, years of hunger and the covariates.

Since hunger often coincides with additional contextual factors such as stress, secondary analyses were performed which added covariates that account for additional early-life stressors. These were three items about the occurrences of earlier periods of stress, poor health and financial hardship.

3. Results

Mean age and percentage of women was 76.2±6.4 and 76.2±6.3 years, and 50% and 51% for participants without and with history of hunger, respectively. Among those exposed to hunger, the mean duration of exposure was 6.2 years. Exposure to hunger

at ages 0-4 years was reported by 281 participants, 441 reported hunger at ages 5-11, 206 reported hunger at 12-18 and 126 reported hunger at ages 19 and above.

Table 1 shows the characteristics of the study participants in wave 4, by age of hunger. It also demonstrates the differences in characteristics between individuals who experienced hunger at the different ages and those who did not have a history of hunger. The results show that these groups significantly differed from each other in terms of age, BMI, number of chronic diseases, depressive symptoms, income, consuming dairy products, fish or chicken and legumes, as well as in delayed recall and numeracy test scores. Lastly, individuals who reported hunger at the ages of 0-4 years experienced hunger for more years, compared to those who experienced hunger at ages 5 and above.

Table 2 presents regression analyses of the associations of hunger, its age periods and duration with later-life cognitive performance. Compared to no experience of hunger, experiencing hunger at ages 0-4 years was related to worse performance on the immediate and delayed memory tests, as well as on the fluency and numeracy tests, even after controlling for potential confounders including age, sex, education, current life-style, health status, financial status and nutrition (Model 2). However, after an additional adjustment for years of hunger this association remained significant only for immediate and delayed recall (Model 4). Hunger in ages 5-11 was significantly associated with lower scores in immediate and delayed recall and in fluency after controlling for age, sex and education (Model 1) but attenuated and became non-significant after additional adjustment for current life-style and health variables (Model 2). Hunger at ages 12-18 had no statistically significant associations with cognitive function in the first model for all cognitive outcomes. However, after adjustment for current life-style and health parameters, those who experienced hunger at ages 12-18 years showed better cognitive performance in immediate recall and fluency (Model 2).

Additional adjustment for duration of hunger resulted in improved delayed recall among those experiencing hunger at ages 12-18 years (Model 4). Lastly, hunger at ages 19 and above was significantly associated with better numeracy performance after controlling for all the study covariates as well as for years of hunger (Model 4).

Model 3 showed that experiencing more years of hunger was associated with worse cognitive function in all four cognitive outcome variables, even after adjusting for additional confounders (Model 3). This association remained significant in Model 4, after the addition of age of hunger to the model, for immediate recall, fluency and numeracy. It became marginally significant for delayed recall.

Table 3 shows the relationships of hunger, its periods and duration with change in cognitive function between waves 4 and 5. Hunger at ages 0-4 years was not associated with change in cognitive function. Hunger at ages 5-11 years was associated with lower rate of decline in delayed recall, after adjustment for all the study's covariates including years of hunger (Model 4). Hunger at ages 12-18 was not associated with change in cognitive function. Hunger at ages 19+ years was related to a smaller rate of decline in delayed recall performance after adjustment the covariates and duration of hunger (Model 4). In addition, hunger at ages 19+ years was associated with a greater decline in fluency after adjustment for the covariates (Model 2), yet this association attenuated and became non-significant after additional adjustment for hunger duration (Model 4).

Years of experiencing hunger were significantly related to greater decline in cognitive function in immediate and delayed recall (Model 3). However, after additional adjustment for hunger periods the association with immediate recall became non (or marginally) significant (Model 4).

We conducted secondary analyses in which periods of stress, poor health and financial hardship during childhood were added as covariates. This was done to account for the possibility that socially and economically vulnerable people may have been more exposed both to hunger and additional adverse conditions. If hunger is related to other negative conditions, the measure of childhood hunger could partially capture the effect of these conditions on later-life cognition. These additional analyses, presented in Supplementary Tables 1 and 2, showed similar results as the main analyses. That is, after controlling for additional childhood conditions, hunger at early ages and longer periods of hunger were associated with worse cognitive function in later life, and hunger during adolescence and at ages 19+ was associated with better cognition.

4. Discussion

The main finding of our study is that individuals who experienced food deprivation in early childhood may have poorer cognitive performance in late-life, while those who experienced food deprivation during older adolescence and young adulthood may have improved cognitive performance.

According to prior evidence, individuals exposed to food deficiency during childhood face an increased risk for cognitive impairment compared to those who did not experience food deprivation [6]. However, the specific ages in which these effects are evident are less clear. The current study identified early childhood, particularly at ages 0-4 years, as a period in which food deprivation is especially detrimental for future cognitive performance [11,22]. Adequate nutrition in the early years of life can be crucial for brain development, and nutritional deprivation can result in long-term alteration of brain structural and functional development [23]. The fact that early

childhood food deprivation was associated with late-life cognition even after adjustment for education, current health and life-style factors and current nutrition suggests that food deprivation is not merely a marker of better life-style and behavioral choices along the life-span, but rather may have an independent association with late-life cognition. However, we note that these results should be interpreted with some caution as there might be additional confounding factors which we did not observe.

According to our findings, experiencing hunger for longer periods of time emerged as a meaningful factor in older age cognition. Thus, it seems that regardless of age in which the hunger occurred, having more years of food deprivation was related to worse cognitive performance decades later. Interestingly, the effects of hunger periods at ages 0-4 years shrank and even became non-significant after the addition of length of hunger period to the models. This might indicate that some of the effects of early-age hunger stem from the hunger lasting longer at these ages. Indeed, those suffering hunger at ages 0-4 years reported longer periods of hunger (nine years compared to five years in the other age groups). These findings add to previous studies by emphasizing the need to account for the duration of hunger and not only to account for the age in which it was experienced.

An unexpected protective role of food deprivation in older adolescence and young-adulthood emerged in the current analysis. Adults who were exposed to hunger during ages 12-18 years showed better recall and language functions at older ages, and those exposed to hunger at ages 19+ showed better numeracy scores and an improvement in delayed recall over two years. However, it is noteworthy that many of the previous studies that found a negative effect of early life food deprivation focused on earlier ages. One study which similarly found a positive effect of food deprivation during childhood inquired about periods of hunger in childhood, without specifying

certain ages [10]. Thus, one possible explanation for its findings is that when asked about previous experience of hunger, respondents considered hunger at older ages of adolescence. Our results might make more sense when considering the literature which suggest a positive effect of mild stress on cognition [24,25]. It might be possible that hunger periods at relatively later childhood were experienced as less stressful compared to hunger in younger ages. Furthermore, these periods were possibly accompanied by cognitive arousal, as these teenagers might have had to be resourceful in attaining food and to take on more responsibilities within their families.

In line with our cross-sectional results, our longitudinal analyses indicated that longer duration of hunger was related to faster rate of memory decline, as well as some evidence of slower cognitive declines when hunger was experienced in older ages. However, the associations of hunger with change in late-life cognition were less robust compared to the associations with late-life cognitive performance at one point in time. Together, these findings may suggest that food deprivation in early life may not only be linked with brain aging but may at least partly be explained by poorer intellectual capacity in younger ages, which persists into late-life [11,26].

Consistent evidence shows that dietary restrictions may increase lifespan and improve health in a range of organisms [27,28], including through improvement in glucose homeostasis [29] which is, in turn, closely associated with cognitive health [30]. However, age of dietary restriction onset is a major determinant of health consequences, as indicated by findings from nonhuman primates, showing that dietary restriction may be beneficial when implemented in adulthood and does not improve survival when implemented in juveniles [31]. When dietary restriction occurs during the perinatal period, it may contribute to increased susceptibility to late-life disease and dysfunction through developmental programming, in which environmental conditions

in critical plastic windows in early-life can determine life-course trajectories of health and aging [32,33]. The mechanisms underlying developmental programming are not fully understood, however emerging findings point to a possible involvement of cell senescence [34]. Indeed, senescence of specific cell types including Astrocytes [35] and endothelial cells [36] may be implicated in age-related cognitive decline, and therefore may explain our observations. Furthermore, early-life food deprivation may have a lasting effect on accelerated brain aging through alteration of oxidative stress and inflammation levels [37], as well as through life-course accelerated decline in growth hormones such as insulin-like growth factor-1 (IGF-1) [38]. Additional research is warranted to further elucidate the mechanisms underlying our findings, and to explore whether the possible detrimental effect of early life food restriction on cognition can be reversed by improving food quantity and quality [39].

The strengths of the current study include a longitudinal design with a relatively large and diverse sample. The study also has several limitations. Childhood conditions were self-reported, thus misclassification within early life experiences of hunger may have occurred. Nevertheless, because all responders were free of dementia, it is likely that this misclassification is not related to the study's outcomes. Moreover, self-report of childhood living conditions has been shown to be valid [40–42]. Specifically, Havari and Mazzonna [40] verified the validity of subjective assessments about hunger episodes in SHARE. They showed that participants reported more hunger during periods of war and that the hunger episodes were consistent with the macro-economic environment at that time.

Additionally, our findings should be interpreted with caution in light of the potential survivor bias. It is possible that those who have reached late life were healthier adolescents, and this might account for their better cognitive performance in older ages.

However, this interpretation is somewhat less likely since respondents who experienced hunger as young children showed worse cognitive function as older adults. Indeed, if those who survived were the sturdier children, this strengthens our findings – those who suffered from hunger as young children and didn't survive might have performed even worse cognitively in older ages, compared to the current sample.

Another issue worth noting is that the hunger periods were likely accompanied by additional adverse conditions other than the food deprivation itself. Indeed, substantial lack of food can be accompanied by poverty and stress and in our European sample some of the hunger experiences occurred within the context of war [40]. Our secondary analyses took into account childhood periods of stress, poor health and financial hardships, and therefore strengthen the notion that the current findings reflect the effects of hunger. Moreover, this study did not only show the effects of hunger but showed differential effects of the ages and length of hunger. Yet, residual confounding cannot be ruled out, and future research is needed to delve into the mechanisms underlying these associations and differentiate the effects of lack of food itself from other contextual factors.

6. Conclusion

In recent years there is a growing understanding that identifying early-life factors that influence cognitive function among the growing elderly population is of great importance. Our findings show for the first time, that experiencing more years of hunger in childhood is related to poorer cognitive abilities at old age. Furthermore, experiencing hunger at ages 0-4 years is particularly detrimental to late-life cognition, while hunger in adolescence and early adulthood may contribute to improved cognition.

Acknowledgements

The SHARE data collection has been funded by the European Commission through FP5 (QLK6-CT-2001-00360), FP6 (SHARE-I3: RII-CT-2006-062193, COMPARE: CIT5-CT-2005-028857, SHARELIFE: CIT4-CT-2006-028812), FP7 (SHARE-PREP: GA N°211909, SHARE-LEAP: GA N°227822, SHARE M4: GA N°261982) and Horizon 2020 (SHARE-DEV3: GA N°676536, SERISS: GA N°654221) and by DG Employment, Social Affairs & Inclusion. Additional funding from the German Ministry of Education and Research, the Max Planck Society for the Advancement of Science, the U.S. National Institute on Aging (U01_AG09740-13S2, P01_AG005842, P01_AG08291, P30_AG12815, R21_AG025169, Y1-AG-4553-01, IAG_BSR06-11, OGHA_04-064, HHSN271201300071C) and from various national funding sources is gratefully acknowledged(see www.share-project.org).

Conflict of interest

The authors declare that they have no conflict of interest.

Author contributions

Ella Cohn-Schwartz contributed to conceptualization, methodology, formal analysis and original draft preparation. Galit Weinstein contributed to conceptualization, methodology, draft preparation, reviewing and editing of the manuscript.

Research data (data sharing and collaboration)

Our study is a secondary analysis of existing data from the Survey of Health, Ageing and Retirement in Europe (SHARE). Data files and documentation are for public use and available at http://www. share-project.org.

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Table 1: Participants characteristics by age of hunger

	Hunger at age 0-4 (N= 281)	Hunger at age 5-11 (N= 441)	Hunger at age 12-18 (N= 206)	Hunger at age 19+ (N= 126)	No history of hunger (N= 1066)	P-value
Age (years)	72.2 ±4.8	75.5 ±4.2	81.6 ± 4.6	79.2 ± 9.6	76.2 ± 6.4	**<0.001**
Males	144 (51.25%)	229 (51.93%)	98 (47.57%)	52 (41.27%)	533 (50.00%)	0.275
Secondary/high education	124 (46.27%)	184 (43.60%)	103 (52.82%)	61 (49.19%)	475 (46.43%)	0.296
BMI	27.45 ±4.79	27.29 ± 4.56	25.72 ±4.86	26.30 ±5.19	26.55 ±4.14	**<0.001**
Currently smoke	31 (11.19%)	51 (11.67%)	14 (6.93%)	15 (12.40%)	111 (10.53%)	0.418
Number of chronic diseases	1.60 ± 1.31	1.58 ± 1.34	1.71 ± 1.27	1.54 ± 1.30	1.44 ± 1.24	**0.025**
Depression (yes)	106 (38.83%)	147 (33.95%)	78 (39.20%)	46 (38.02%)	260 (25.00%)	**<0.001**
Frequent physical activity[1]	106 ± 38.27	170 ± 38.90	58 ± 28.71	38 ± 31.40	381 ± 36.15	0.092
Income (1st tertile)	65 (23.13%)	154 (34.92%)	65 (31.55%)	51 (40.48%)	374 (35.08%)	0.009
Income (2nd tertile)	111 (39.50%)	142 (32.20%)	78 (37.86%)	37 (29.37%)	340 (31.89%)	
Income (3rd tertile)	105 (37.37%)	145 (32.88%)	63 (30.58%)	38 (30.16%)	352 (33.02%)	
Servings of fruit or vegetables[2]	4.74 ± 0.66	4.66 ±0.71	4.72 ±0.63	4.61 ±0.76	4.73 ±0.64	0.203
Servings of dairy products[2]	4.52 ±0.99	4.44 ±1.01	4.59 ±0.83	4.36 ±1.05	4.58 ±0.88	**0.025**
Servings of meat, fish or chicken[2]	3.93 ±0.91	4.03 ±0.86	4.00 ±0.97	4.07 ±1.01	4.26 ±0.84	**<0.001**
Servings of legumes or eggs[2]	3.33 ±1.16	3.33 ±1.16	3.39 ±1.21	3.27 ±1.26	3.17 ±1.23	**0.031**
Immediate Recall	4.38 ±1.83	4.49 ±1.78	4.48 ±1.70	4.52 ±1.87	4.65 ±1.77	0.143
Delayed recall	2.90 ±2.13	2.99 ±2.05	3.09 ±1.93	2.98 ±2.25	3.29 ±2.06	**0.015**
Fluency	16.71 ±6.85	16.66 ±6.85	17.06 ±6.39	17.12 ±6.84	17.37 ±6.24	0.309
Success in the Numeracy test	117 (52.94)	214 (58.31)	108 (62.43)	73 (65.77)	603 (63.27)	**0.034**
Hunger years	8.97 ±6.35	5.48 ±3.32	4.89 ±5.02	5.03 ±5.08	-	**<0.001**

Values are mean±SD or N (%)

[1] Once a week or more

[2] Per week

Table 2: Association of hunger at different age groups and duration of hunger with cognitive function

		Model 1		Model 2		Model 3		Model 4	
Cognitive test	**Age of hunger (years)**	**B±SE**	**P value**	**B ±SE**	**P value**	**B ±SE**	**P value**	**B±SE**	**P value**
Immediate recall	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.58±0.12	**<0.001**	-0.50±0.12	**<0.001**			**-0.31±0.15**	**0.043**
	5-11	-0.20±0.10	**0.033**	-0.12±0.10	0.194			0.00±0.11	0.997
	12-18	0.14±0.13	0.284	0.28±0.14	**0.043**			0.38±0.15	**0.010**
	19+	0.01±0.16	0.963	0.10±0.16	0.536			0.22±0.17	0.191
	Hunger years					-0.03±0.01	**<0.001**	-0.02±0.01	**0.049**
Delayed recall	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.74±0.13	**<0.001**	-0.62±0.13	**<0.001**			-0.40±0.18	**0.023**
	5-11	-0.33±0.11	**0.003**	-0.21±0.11	0.061			-0.07±0.13	0.589
	12-18	0.15±0.15	0.320	0.27±0.16	0.089			0.37±0.17	**0.026**
	19+	-0.19±0.18	0.288	-0.14±0.18	0.458			-0.00±0.20	0.995
	Hunger years					-0.04±0.01	**<0.001**	-0.02±0.01	0.064
Fluency	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-1.60±0.42	**<0.001**	-1.20±0.43	**0.005**			-0.34±0.56	0.545
	5-11	-0.80±0.35	**0.021**	-0.54±0.35	0.127			0.04±0.42	0.930
	12-18	0.65±0.49	0.183	1.10±0.50	**0.028**			1.57±0.53	**0.003**
	19+	0.19±0.58	0.748	0.53±0.59	0.366			1.08±0.63	0.084
	Hunger years					-0.10±0.03	**0.002**	-0.10±0.04	**0.014**
Numeracy		**OR (95% CI)**		**OR (95% CI)**		**OR (95% CI)**		**OR (95% CI)**	
	No hunger	1.00 (ref.)		1.00 (ref.)				1.00 (ref.)	
	0-4	**0.57 (0.42-0.79)**		**0.63 (0.45-0.88)**				0.83 (0.54-1.30)	
	5-11	0.79 (0.61-1.03)		0.88 (0.67-1.15)				1.06 (0.76-1.48)	

	12-18	0.97 (0.68-1.40)	1.07 (0.73-1.57)		1.24 (0.82-1.88)
	19+	1.21 (0.78-1.85)	1.41 (0.89-2.24)		**1.77 (1.07-2.91)**
	Hunger years			**0.97 (0.94-0.99)**	**0.96 (0.93-1.00)**

Model 1: adjusted for age, gender and education
Model 2+3: model 1 + Body mass index, physical activity, smoking, chronic diseases, depression, income, consumption of vegetables, consumption of dairy, consumption of mean and consumption of legumes.
Model 4: model 2 + hunger years

Table 3: Association of hunger at different age groups and duration of hunger with change in cognitive function

		Model 1		Model 2		Model 3		Model 4	
Cognitive test	**Age (years)**	**B±SE**	**P value**	**B ±SE**	**P value**	**B ±SE**	**P value**	**B±SE**	**P value**
Immediate recall	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.12±0.12	0.329	-0.10±0.12	0.408			0.11±0.17	0.499
	5-11	-0.12±0.10	0.226	-0.09±0.10	0.346			0.05±0.12	0.684
	12-18	-0.09±0.14	0.516	-0.07±0.14	0.652			0.04±0.15	0.813
	19+	-0.17±0.17	0.301	-0.15±0.17	0.388			-0.03±0.18	0.894
	Hunger years					-0.02±0.01	**0.032**	-0.03±0.01	0.061
Delayed recall	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.05±0.14	0.688	-0.07±0.14	0.610			0.037±0.19	0.054
	5-11	0.06±0.11	0.590	0.05±0.11	0.669			0.33±0.14	**0.018**
	12-18	-0.01±0.16	0.965	0.01±0.17	0.955			0.22±0.18	0.207
	19+	0.26±0.19	0.165	0.26±0.19	0.197			0.52±0.21	**0.015**
	Hunger years					-0.02±0.01	**0.027**	-0.05±0.02	**<0.001**
Fluency	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.06±0.42	0.884	0.12±0.44	0.781			0.56±0.60	0.356
	5-11	-0.19±0.34	0.585	-0.10±0.36	0.779			0.19±0.44	0.676
	12-18	-0.46±0.49	0.346	-0.28±0.52	0.594			-0.08±0.55	0.888
	19+	-1.15±0.60	0.054	-1.23±0.62	**0.048**			-0.10±0.67	0.141
	Hunger years					-0.03±0.03	0.334	-0.05±0.05	0.296
numeracy		**OR (95% CI)**		**OR (95% CI)**		**OR (95% CI)**		**OR (95% CI)**	
	No hunger	1.00 (ref.)		1.00 (ref.)				1.00 (ref.)	
	0-4	0.73 (0.48-1.11)		0.78 (0.51-1.19)				0.78 (0.44-1.38)	
	5-11	0.82 (0.59-1.13)		0.80 (0.57-1.11)				0.80 (0.53-1.21)	

	12-18	0.62 (0.39-0.96)	0.67 (0.42-1.07)		0.68 (0.41-1.12)
	19+	0.92 (0.54-1.59)	0.99 (0.56-1.74)		0.99 (0.54-1.84)
	Hunger years			0.98 (0.95-1.01)	1.00 (0.95-1.05)

Model 1: adjusted for age, gender and education
Model 2+3: model 1 + Body mass index, physical activity, smoking, chronic diseases, depression, income, consumption of vegetables, consumption of dairy, consumption of mean and consumption of legumes.
Model 4: model 2 + hunger years

Supplementary Table 1: Association of hunger at different age groups and duration of hunger with cognitive function– including covariates of earlier periods of stress, poor health and financial hardship

		Model 1		Model 2		Model 3		Model 4	
Cognitive test	**Age of hunger\years**	**B±SE**	**P value**	**B ±SE**	**P value**	**B ±SE**	**P value**	**B±SE**	**P value**
Immediate recall	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.58±0.12	**<0.001**	-0.54±0.12	**<0.001**			-0.35±0.15	**0.022**
	5-11	-0.20±0.10	**0.033**	-0.17±0.10	0.072			-0.05±0.12	0.677
	12-18	0.14±0.13	0.284	0.22±0.14	0.116			0.32±0.15	**0.031**
	19+	0.01±0.16	0.963	0.03±0.16	0.842			0.16±0.17	0.361
	Hunger years					-0.03±0.01	**<0.001**	-0.02±0.01	**0.050**
Delayed recall	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.74±0.13	**<0.001**	-0.65±0.14	**<0.001**			-0.44±0.18	**0.013**
	5-11	-0.33±0.11	**0.003**	-0.28±0.11	**0.013**			-0.14±0.13	0.296
	12-18	0.15±0.15	0.320	0.19±0.16	0.233			0.30±0.17	0.077
	19+	-0.19±0.18	0.288	-0.23±0.19	0.217			-0.10±0.20	0.641
	Hunger years					-0.04±0.01	**<0.001**	-0.03±0.01	0.063
Fluency	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-1.60±0.42	**<0.001**	-1.35±0.43	**0.002**			-0.41±0.56	0.465
	5-11	-0.80±0.35	**0.021**	-0.69±0.36	0.054			-0.05±0.42	0.905
	12-18	0.65±0.49	0.183	0.86±0.50	0.086			1.39±0.54	**0.010**
	19+	0.19±0.58	0.748	0.22±0.59	0.712			0.82±0.63	0.192
	Hunger years					-0.12±0.03	**<0.001**	-0.12±0.04	**0.007**
numeracy		**OR (95% CI)**		**OR (95% CI)**		**OR (95% CI)**		**OR (95% CI)**	
	No hunger	1.00 (ref.)		1.00 (ref.)				1.00 (ref.)	
	0-4	**0.57 (0.42-0.79)**		**0.64 (0.45-0.89)**				0.84 (0.54-1.31)	
	5-11	0.79 (0.61-1.03)		0.85 (0.65-1.12)				1.03 (0.74-1.44)	
	12-18	0.97 (0.68-1.40)		1.04 (0.71-1.54)				1.21 (0.80-1.83)	
	19+	1.21 (0.78-1.85)		1.40 (0.88-2.22)				**1.75 (1.06-2.89)**	
	Hunger years					**0.96 (0.94-0.99)**		**0.96 (0.93-1.00)**	

Model 1: adjusted for age, gender and education

Model 2+3: model 1 + Body mass index, physical activity, smoking, chronic diseases, depression, income, consumption of vegetables, consumption of dairy, consumption of mean and consumption of legumes, early periods of stress, early periods of poor health, early periods of financial hardship.
Model 4: model 2 + hunger years

Supplementary Table 2: Association of hunger at different age groups and duration of hunger with change in cognitive function – including covariates of earlier periods of stress, poor health and financial hardship

		Model 1		Model 2		Model 3		Model 4	
Cognitive test	**Age (years)**	**B±SE**	**P value**	**B ±SE**	**P value**	**B ±SE**	**P value**	**B±SE**	**P value**
Immediate recall	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.12±0.12	0.329	-0.14±0.12	0265			0.09±0.17	0.587
	5-11	-0.12±0.10	0.226	-0.14±0.10	0.156			0.01±0.13	0.909
	12-18	-0.09±0.14	0.516	-0.15±0.15	0.313			-0.03±0.16	0.829
	19+	-0.17±0.17	0.301	-0.22±0.17	0.200			-0.09±0.19	0.648
	Hunger years					-0.03±0.01	**0.009**	-0.03±0.014	**0.048**
Delayed recall	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.05±0.14	0.688	-0.12±0.14	0.412			0.36±0.19	0.064
	5-11	0.06±0.11	0.590	-0.01±0.12	0.945			0.30±0.14	**0.034**
	12-18	-0.01±0.16	0.965	-0.10±0.17	0.555			0.14±0.18	0.445
	19+	0.26±0.19	0.165	0.15±0.19	0.468			0.43±0.21	**0.043**
	Hunger years					-0.03±0.01	**0.005**	-0.06±0.02	**<0.001**
Fluency	No hunger	0.00 (ref.)		0.00 (ref.)				0.00 (ref.)	
	0-4	-0.06±0.42	0.884	0.02±0.44	0.956			0.74±0.60	0.216
	5-11	-0.19±0.34	0.585	-0.28±0.36	0.440			0.23±0.45	0.606
	12-18	-0.46±0.49	0.346	-0.56±0.52	0.279			-0.19±0.56	0.733
	19+	-1.15±0.59	0.054	-1.47±0.62	**0.019**			-1.01±0.67	0.133
	Hunger years					-0.07±0.03	0.053	-0.09±0.05	0.064
numeracy		**OR (95% CI)**		**OR (95% CI)**		**OR (95% CI)**		**OR (95% CI)**	
	No hunger	1.00 (ref.)		1.00 (ref.)				1.00 (ref.)	
	0-4	0.73 (0.48-1.11)		0.77 (0.50-1.18)				0.73 (0.41-1.31)	
	5-11	0.82 (0.59-1.13)		0.77 (0.55-1.07)				0.75 (0.49-1.14)	
	12-18	**0.62 (0.39-0.96)**		**0.62 (0.38-0.99)**				0.60 (0.36-1.01)	
	19+	0.92 (0.54-1.59)		0.93(0.53-1.65)				0.91 (0.49-1.69)	
	Hunger years					0.98 (0.94-1.01)		1.01 (0.95-1.06)	

Model 1: adjusted for age, gender and education

Model 2+3: model 1 + Body mass index, physical activity, smoking, chronic diseases, depression, income, consumption of vegetables, consumption of dairy, consumption of mean and consumption of legumes, early periods of stress, early periods of poor health, early periods of financial hardship.
Model 4: model 2 + hunger years