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Childhood nutritional deprivation and cognitive impairment among older Chinese people

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A B S T R A C T

Late-life cognitive impairment may have its origins in childhood. Here, we examine the associations between markers of childhood nutritional deprivation and cognitive impairment in older adults. We made use of the 2002 and 2005 waves of the Chinese Longitudinal Healthy Longevity Survey to examine these associations for persons aged 65–105 ($N = 15{,}444$). Anthropometric measures (arm length, knee height) and self-reported hunger were used to measure early-life nutritional deficiencies. Cognitive impairment was measured using the Chinese version of the Mini Mental State Examination. Results from multivariate logistic regression models show that both anthropometric measures and self-report markers of early-life nutritional status were significantly associated with the odds of cognitive impairment at baseline for both men and women after controlling for age and ethnicity. Adjustments for childhood and adulthood socioeconomic status, adulthood health, and lifestyle habits had little effect on these associations except for the effect of hunger among men. Results from multinomial logistic regression models show that during the three-year follow-up period, arm length was significantly associated with the onset of cognitive impairment after controlling for various confounders in men, but not in women. Our findings suggest that early-life nutritional deprivation may contribute to cognitive impairment among older Chinese adults.

Background

Undernutrition in infancy and childhood has clear negative consequences for children's cognitive development. However, it is less clear whether this adverse effect persists into adolescence, adulthood, and old age (Case & Paxson, 2008; Mendez & Adair, 1999) as an individual's cognitive functioning continues to develop over the life span. Recent studies in the U.S., England, Israel, and Korea demonstrate the plausibility of this association, reporting that limb length (arm span, knee height, leg length, and height), a marker of early childhood growth and development, is inversely associated with cognitive impairment, cognitive decline, and Alzheimer's disease late in life (Abbott et al., 1998; Beeri et al., 2005; Huang et al., 2008; Jeong et al., 2005; Petot et al., 2007). However, relatively little is known about whether this association exists in developing countries, where early-life conditions and the prevalences of hunger and stunting are much worse than in developed countries. In 2009, two regional studies in southern China found that daily milk drinking in childhood and greater height were positively associated with mid- to late-life cognitive function (Heys et al., 2009; Zhang et al., 2009). This study contributes to this line of research by investigating the associations between markers of early-life nutritional deprivation and cognitive impairment among a nationwide random sample of adults aged 65 and over in China at baseline and during a three-year follow-up. The older Chinese population has experienced extraordinary levels of undernutrition on a broad scale compared with most developed countries in the 20th century.

Until recently, most research has focused on the impact of early-life undernutrition on physical health and mortality, with much less attention devoted to its long-term, cumulative negative effects on cognitive functioning. This issue is especially important for developing countries, where a large proportion of the current cohort of older adults has experienced childhood poverty, hunger, and exposure to infectious diseases.

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Childhood nutritional deprivation and cognitive function in late-life

Increasingly, the life course approach has been used to evaluate the determinants of cognitive functioning in late-life. Cumulative disadvantage theory posits that insults throughout the life course (e.g., childhood poverty, illness and unhealthy behavior, physically demanding jobs) can accumulate and negatively affect people's health in late-life. The theory also suggests that early risk factors can be compounded across the life course by setting people onto different life trajectories such that earlier disadvantages lead to later disadvantages, which results in increasing health inequalities in later life (Crystal & Shea, 1990; Haas, 2008; O'Rand & Hamil-Luker, 2005).

Although prior research has shown that both early-life and late-life conditions are associated with older adults' cognitive functioning, the evidence for the pathways through which early-life factors affect later life cognition is less clear. The critical period hypothesis posits that undernutrition in early-life impairs brain development and leads to less efficient brain function because of "less myelin, less branching of dendrites, and less developed connectivity patterns" (Moceri, Kukull, Emanuel, van Belle, & Larson, 2000, p. 415). The negative effects of the impaired brain development may be small until they are aggravated by the aging process (Moceri et al., 2000). A recent study found that lower childhood cognitive ability was associated with the development of late-onset dementia, suggesting that cognitive deficits in early-life may put individuals at higher risk of cognitive impairment in late-life (Deary, Whiteman, Starr, Whalley, & Fox, 2004). Thus, nutritional deprivation during developmentally important periods (*in utero* and early childhood) may have *long-term* negative effects on cognitive function. Due to data limitations, few researchers have been able to develop a strong test of this idea because of the lack of data on the childhood cognitive functioning of their older respondents. Two studies took advantage of longitudinal data to investigate whether early-life nutritional deprivation was associated with late-life cognitive decline and reported conflicting findings. Mak, Kim, and Stewart (2006) found, among a sample of 290 African-Caribbean residents of south London, that shorter leg length was associated with cognitive impairment at baseline but not associated with cognitive decline over a three-year follow-up. In contrast, using a national sample with an average of 5.4 years of follow-up in the U.S., Huang et al. (2008) reported that a longer arm span was associated with lower dementia incidence for both men and women.

The pathway model is an alternative hypothesis that emphasizes mechanisms wherein nutritional disadvantages in early-life *indirectly* influence late-life cognition via social conditions and health problems related to cognitive functioning. For example, a large body of research has reported an inverse relationship between education and late-life cognition as measured by cognitive tests, cognitive decline, or dementia (Cagney & Lauderdale, 2002; Zhang et al., 1990). Researchers have argued that education in early-life promotes brain growth in the formative years and enables the brain network to operate more efficiently, thus providing protection against cognitive decline in later life (Fritsch et al., 2007; Kaplan et al., 2001). Malnourished children might lack the energy and motor skills essential to thrive in school and thus complete fewer years of schooling, which in turn affects late-life cognition (Mendez & Adair, 1999). In addition, higher levels of education often lead to occupations that involve cognitive challenges and practice, which could further enhance – or maintain – cognitive functioning in adulthood (Andel, Kareholt, Parker, Thorslund, & Gatz, 2007; Schooler, 1987). Finally, the research linking early-life nutritional deficiencies with cardiovascular and metabolic conditions points to possible physical disease pathways. Cardiovascular and metabolic conditions are both associated with cognitive impairment, suggesting that early-life nutrition may set in motion a cascade of physical health problems resulting in cognitive impairment (National Research Council, 2000). Most recently, Case and Paxson (2008) found some support for the pathway model. Especially noteworthy in their results was the reduction in the association between height and five out of six domains of cognitive functioning when education was controlled for. Their results provided substantially less evidence for occupation and physical health conditions as mechanisms linking early-life nutritional status and cognitive function. In reality, the mechanisms suggested in the critical period and pathway hypothesis may operate together in complex ways to determine cognitive functioning in later life.

The current study

Our focus on China provides a more global perspective on the association between early-life nutritional deprivation and late-life cognitive functioning. Many of China's surviving older individuals suffered from hunger and devastating wars in their childhood (Zeng, Gu, & Land, 2007). Before 1949, for example, the life expectancy at birth in China was 35 years (China Internet Information Center, 2008). We take advantage of a large longitudinal population-based survey conducted in China that includes two markers of early-life nutritional status: the anthropometric measures of arm length and knee height and self-reported experience with hunger in childhood. Prior population-level studies of the effects of nutritional deprivation have often relied solely on adult anthropometry (Abbott et al., 1998; Huang et al., 2008), except for a recent study by Zhang et al. (2009). The advantage of multiple indicators is that the anthropometric measures may best capture nutritional deprivation in the early stages of growth because differences in knee height seem to be largely determined in the first two years of life (Huang et al., 2008), while self-reported hunger most likely captures nutritional deprivation and catch-up growth later in childhood, when the person has become able to remember those experiences (Adair, 1999). In the study, we hypothesized, first, that childhood nutritional deprivation would be associated with increased odds of cognitive impairment at baseline and onset over the three-year follow-up period. Second, the effect of childhood nutritional deprivation on cognitive impairment would be reduced after controlling for adult SES and other adult factors.

Methods

Sample

The Chinese Longitudinal Healthy Longevity Survey (CLHLS) began in 1998 and was distributed in one randomly selected half of the counties and cities in 22 of China's 31 provinces. The surveyed areas covered about 85% of the total Chinese population. Local aging committees provided lists of centenarians in randomly selected counties/cities, including persons residing in institutions. For each centenarian with a pre-designated random code, one nearby octogenarian and one nearby nonagenarian of pre-designated age and sex were interviewed. The term 'nearby' mainly indicated the same village or street, if applicable, or the same town, county, or city. The aim of this special sampling technique was to produce comparable numbers of randomly selected male and female octogenarians and nonagenarians at each age from 80 to 99. We made use of the third and fourth waves, collected in 2002 and 2005, respectively, because the sample was extended to include the elderly aged 65 to 79 as a comparison with the oldest old beginning in 2002. The technique used for sampling the young elderly was similar to the technique discussed above for those aged 80 to 99. Importantly for our analysis, an enumerator and a nurse or medical school student conducted the interview and performed a basic health examination at each interviewee's home; the anthropometric measures used in our analysis were obtained in this manner. A detailed description of the sampling design and data quality of the CLHLS appears elsewhere (Gu, 2008).

This study focuses on respondents aged 65 to 105 years in 2002. Those who reported being aged 106 or older were excluded because of insufficient information available to validate their extremely old age (Zeng, Vaupel, Xiao, Zhang, & Liu, 2002). We also excluded 354 respondents who were cognitively impaired in 2002 but became cognitively normal in 2005 based on their scores on the cognitive test. Because the reason behind this change was not clear, we excluded these respondents from our final sample. Inclusion of these 354 respondents produced similar results. Our final sample included 15,444 respondents in 2002. The analytical sample for the onset of cognitive impairment from 2002 to 2005 was restricted to 12,087 respondents whose cognition was considered normal in 2002. Of these respondents, 1157 (10%) experienced the onset of cognitive impairment during the three-year interval; 3411 (28%) died; and 1549 (13%) were lost to follow-up or could not take the cognitive test at follow-up for various reasons.

Outcome variable

Cognitive impairment

Cognitive function was measured using the Chinese version of the Mini Mental State Examination (MMSE). The MMSE is adapted from the scale developed by Folstein and colleagues and tests four aspects of functioning: orientation, calculation, recall, and language (Folstein, Folstein, & McHugh, 1975). The Chinese version of the MMSE reflects the cultural and socioeconomic conditions among the older adults in China and uses questions that are easily understandable and practically answerable among participants whose cognitive functioning is normal (Zeng et al., 2002). Several similar versions of the Chinese MMSE, all of which were adapted from Folstein and colleagues, have been used in China and found to be reliable and valid for use with Chinese older persons (Yu et al., 1989; Zhang et al., 2006). A more detailed description of the Chinese version of the MMSE appears elsewhere (Zhang, 2006).

Unlike other questions in the CLHLS that could be answered by a proxy (e.g., a spouse or family member), all MMSE questions must be answered by the sampled person. There are three possible answers for each question: correct, wrong, and unable to answer. About 2% of respondents were unable to answer some of the questions due to low cognitive functioning as indicated by the interviewer. We coded these answers as wrong (i.e., a score of 0). An additional 2% were unable to answer any of the questions and 8% were unable to answer some of the questions due to hearing problems, sickness, or other reasons. Consistent with previous studies, we found that the level of "unable to answer" was much higher for the relatively difficult tasks compared with the relatively easy tasks (Herzog & Wallace, 1997). We evaluated three alternative approaches to assess how best to handle the responses of "unable to answer": (1) coding them as missing values and using multiple imputation; (2) excluding respondents with "unable to answer" from the analysis; and (3) coding responses of "unable to answer" as incorrect answers. The three sets of results were very similar, and the results shown below are based on the third approach.

The total possible score on the MMSE is 30, with lower scores indicating poorer cognitive ability. For the current sample, the reliability of the MMSE was high (Cronbach's $\alpha = 0.98$). According to Folstein et al. (1975), there are four levels of cognitive functioning: cognition severely impaired (score 0–9), moderately impaired (score 10–17), slightly impaired (score 18–23), and unimpaired (score 24–30). Therefore, respondents in this paper were defined as having moderate to severe cognitive impairment (hereafter *cognitive impairment*) in 2002 if their scores on the MMSE were less than 18 (Nguyen, Black, Ray, Espino, & Markides, 2003; Yu et al., 1989). The onset of cognitive impairment within the approximately three-year interval of the study (2002–2005) was based on whether MMSE scores for respondents whose cognition was considered normal at baseline fell below 18 at follow-up. The dependent variable in the longitudinal model has four outcomes: cognitively impaired, death, loss to follow-up, and cognitively normal (the reference category). Previous clinical studies in China have also validated the use of 18 or 19 as a cutoff point for screening for dementia among populations with little or no formal education (Zhang et al., 1998, 2006). We also found that our results were insensitive to varying the cutoff point up or down by one unit.

Explanatory variables

Childhood nutritional deprivation

Childhood nutritional deprivation is indexed by three variables: arm length, knee height, and whether the individual frequently went to bed hungry in childhood (up to age 14). Previous studies have documented that childhood height is strongly associated with adult height (Wadsworth, Hardy, Paul, Marshall, & Cole, 2002). Without data on height in early adulthood, anthropometric measures in late adulthood are often treated as a proxy of early-life nutritional intake (Abbott et al., 1998; Jeong et al., 2005). Prior research has also shown that among older adults, arm length is a more accurate representation of earlier stature than height, which is significantly affected by degenerative processes in old age such as osteoporotic kyphosis (Jeong et al., 2005). Arm length in this study was measured by the arm span from the uppermost part of the shoulder along the outstretched arm to the wrist. The measurement was taken on the right arm. We classified respondents into two categories (arm length below the lowest 10th percentile vs. arm length above the lowest 10th percentile) by sex. Our initial analysis revealed that the results were similar if we used quintiles or quartiles.

In order to compare our results with studies that use knee height as a proxy for early-life nutritional status, we also evaluated how cognitive functioning is associated with knee height. CLHLS respondents were asked to take off their shoes, put their right foot on the ground, and bend their right calf and right thigh into a 90° angle. The nurse or medical student then put a level plastic board or thick piece of paper on the right thigh and measured its height from the ground with a ruler. Both arm length and knee height were measured to the nearest 1 cm.

Responses to *frequently went to bed hungry in childhood* were recorded as yes or no (*went to bed hungry* = 1). Approximately 20% of respondents used a proxy reporter when the respondent was unable to answer this question for various reasons (e.g., cognitively impaired). Additional analyses were conducted to test for potential effects of proxy reports, but we did not find that they made a difference in our results.

Childhood socioeconomic conditions

Other early-life conditions are indexed by two variables: place of birth and education. Place of birth refers to self-reported urban or rural birthplace. Rural residents were disadvantaged in China in key ways, including the quality of education, access to good jobs, health care, and overall standard of living, compared with their urban counterparts (Zhu & Xie, 2007; Zimmer & Kwong, 2004). Rural/urban residence at birth thus reflects the general individual and community socioeconomic conditions of a respondent's childhood. Because educational opportunities in the early 20th century were mainly restricted to families with higher SES (Zeng et al., 2007), we included the respondent's education as another indicator of childhood conditions. We classified education into three categories: 0 years of schooling, 1–6 years, and 7 years or more (reference category).

Adult conditions

Adult conditions were measured by respondents' or their spouses' occupation before age 60 (*manual* = 1), current residence (*rural* = 1), marital status (*unmarried* = 1), smoking (*current smoker* = 1), selected chronic diseases, and ADL disability. Respondents were classified as either having or not having the following five diseases: hypertension, heart disease, cerebrovascular disease, stroke, and diabetes. All of these conditions have been associated with an increased risk of cognitive impairment. Persons were defined as "ADL disabled" if they reported that they could not perform one or more of the following activities independently: bathing, dressing, eating, indoor transferring, toileting, and continence.

Other covariates

We included age, age squared, and ethnicity (*Non-Han* = 1). All independent variables came from the 2002 wave of the CLHLS.

Analytical strategy

We began with a descriptive analysis of all variables by gender, followed by bivariate analyses of markers of childhood nutritional deprivation and other covariates using chi-square tests and *t*-tests. Next, we estimated gender-specific models because previous research suggests that early-life risk factors may operate differently for health conditions associated with cognitive impairment (Haan & Wallace, 2004; Hamil-Luker & O'Rand, 2007). Our preliminary analysis showed a statistically significant interaction between gender and childhood nutritional deprivation in modeling the onset of cognitive impairment during the follow-up. Logistic regression was used to model how early-life nutritional deprivation (arm length and hunger) was associated with cognitive impairment. We present three models each for men and women, respectively, in Table 2: Model I adjusts for age, age squared, and ethnicity; Model II additionally adjusts for childhood SES; and Model III adjusts for all of the covariates in Model II, as well as adult conditions, including occupation, current residence, marital status, smoking, chronic diseases, and ADL disability. For the purpose of comparison with prior studies that used knee height as an indicator of early-life nutritional status, we re-estimated these models, replacing arm length with knee height in all models. Results are reported in Table 3. We used multinomial logistic regression to examine the association between early-life nutritional deprivation and the onset of cognitive impairment during the three-year follow-up. Again, early-life nutritional deprivation indicators were entered first in Model I, controlling for age, age squared, and ethnicity; childhood SES measures were added in Model II; and Model III additionally adjusted for adulthood SES and other adulthood factors. Results are reported in Tables 4 and 5. Because the sampling weights in the data set were solely a function of the three major independent variables (i.e., age, gender, and current residence) used in the analysis, we present the unweighted estimates because they are unbiased and consistent (Winship & Radbill, 1994).

Overall, there is little to no missing data for the independent variables (the highest rate of missing data was around 1.3% for knee height). To reduce the influence of missing items on our data analysis and inferences, we used a multiple imputation approach to fill in missing values (Allison, 2001). The results are based on ten random, multiple-imputed replicates. All analyses were performed using Stata version 10.1.

Results

Table 1 presents summary statistics on the characteristics of the sampled elderly Chinese individuals included in the study. Around 63.3% of men and 65.5% of women reported that they often went to bed hungry in childhood, demonstrating the prevalence of nutritional challenges in this population. Among women, shorter arm length was associated with rural birthplace, having fewer years of education, currently living in rural areas, self or spouse having had manual jobs, older age, being Han, having none of the selected diseases, and having ADL disabilities; shorter knee height was associated with having fewer years of education, older age, being Han, being unmarried, not smoking, and having ADL disabilities. Among men, shorter arm length was associated with having fewer years of education, currently living in rural areas, self or spouse having had manual jobs, and having ADL disabilities; shorter knee height was associated with having fewer years of education, currently living in rural areas, self or spouse having had manual jobs, older age, being unmarried, and having ADL disabilities. Going to bed hungry was associated with rural birthplace, fewer years of education, currently living in rural areas, self or spouse having had manual jobs, age, and having none of the selected chronic diseases for both men and women. On the whole, these results are consistent with the idea that early-life nutritional deficiencies, as reflected in the anthropometric and self-reported proxy measures, are associated with measures reflecting possible achievement and health pathways with a few exceptions.

As shown in Table 2, at baseline, markers of early-life nutritional status were significantly associated with odds of cognitive impairment in later life. In Model I (adjusted for age, age squared, and ethnicity), older men with arm length below the 10th percentile had a 67% higher risk of being cognitively impaired than other men. Those who frequently went to bed hungry in childhood were 29% more likely to be cognitively impaired. In Model II, we added indicators of childhood SES and found that the odds ratio for arm length changed little and remained statistically significant. However, the effect of childhood hunger was reduced and became statistically insignificant. In Model III, we added adulthood SES and other covariates, and the odds ratio for arm length was reduced slightly. Among older women, we also found positive associations between markers of childhood nutritional deprivation and cognitive impairment. In Model I, older women with arm length below the 10th percentile had a 47% higher risk of being cognitively impaired than other women, and those who frequently went to bed hungry in childhood were 35% more likely to be cognitively impaired. These associations remained robust after controlling for childhood and adulthood conditions.

As for the effects of covariates, education, currently living in rural areas, age, being single, and ADL disability were significantly associated with higher odds of cognitive impairment for men and women. In addition, having selected chronic diseases was associated with cognitive impairment among men.

As noted above, these models were re-estimated substituting knee height for arm length (see Table 3). The results for Model I

Table 1
Sample characteristics of older Chinese participants by arm length, knee height, and childhood hunger: CLHLS, 2002.

	Gender, %[a]		Arm length lowest 10th percentile, %[b]		Knee height lowest 10th percentile, %[b]		Went to bed hungry, %[b]	
	Men ($n = 6676$)	Women ($n = 8768$)	Men ($n = 6676$)	Women ($n = 8768$)	Men ($n = 6676$)	Women ($n = 8768$)	Men ($n = 6676$)	Women ($n = 8768$)
Total	100.0	100.0	10.6	9.6	10.9	10.6	63.3	65.5
Childhood SES								
Born in rural area								
No	16.2	15.4	10.1	7.9	11.3	10.6	45.9	45.5
Yes	83.8	84.6	10.7	9.9	10.8	10.6	66.7	69.2
P				*			**	**
Years of schooling								
7+ years	18.2	3.8	8.4	6.0	8.6	5.1	40.6	24.9
1–6 years	47.7	14.2	10.9	8.0	10.6	8.8	63.3	51.8
0 year	34.1	82.0	11.3	10.0	12.5	11.2	75.5	69.7
P	**		*	**	**	**	**	**
Adulthood SES								
Living in rural area								
No	46.7	45.9	9.1	8.8	9.9	10.8	55.8	57.5
Yes	53.3	54.1	11.9	11.9	11.8	10.5	69.9	72.3
P			**	*	*		**	**
Manual occupation of self or spouse								
No	40.0	23.0	9.0	7.7	9.6	9.8	52.0	46.9
Yes	60.0	77.0	11.6	10.1	11.7	10.8	70.9	71.1
P	**		**	**	**		**	**
Other covariates								
Average age	83.6	87.9	–	–	–	–	–	–
P	**							
Age								
65–79	36.3	27.1	9.7	7.0	9.6	7.6	64.4	66.0
80–89	31.3	23.1	11.2	8.6	11.0	10.0	60.8	63.0
90–99	23.1	23.8	10.8	11.0	11.9	11.4	62.4	63.0
100+	9.3	26.0	11.2	11.8	13.2	13.5	70.0	69.4
P	**			**	*	**	**	**
Ethnicity								
Han	95.0	94.1	10.6	9.8	11.0	10.9	63.2	65.4
Non-Han	5.0	5.9	9.3	6.0	8.1	6.6	65.0	67.1
P	*			**		**		
Unmarried								
No	50.0	18.1	9.9	8.6	9.9	9.2	62.5	64.4
Yes	50.0	81.9	11.3	9.8	11.8	10.9	64.2	65.7
P	**				*	*		
Currently smoking								
No	66.8	92.7	10.1	9.7	10.9	10.8	62.1	65.6
Yes	33.2	7.3	11.5	7.5	11.0	8.1	65.8	64.2
P	**					*	**	
Having selected diseases								
No	75.0	75.7	10.8	10.0	10.8	10.8	64.2	66.4
Yes	25.0	24.3	10.0	8.4	11.2	10.0	60.6	62.6
P				*			**	**
ADL disabled								
No	78.1	64.0	10.2	8.2	10.3	9.1	63.6	65.7
Yes	21.9	36.0	12.1	12.1	12.9	13.3	62.5	65.2
P	**		*	**	**	**		

Note: (1) Data in the table are unweighted. (2) [a]*P* values reflect significant differences between women and men; [b]*P* values reflect significant differences within women or men. $^{*}p < 0.05$; $^{**}p < 0.01$.

showed that older men with knee heights below the 10th percentile were 18% more likely to have cognitive impairment than other men, but the effect was not statistically significant. Those who went to bed hungry as children were 29% more likely to have cognitive impairment. We found similar associations among women, and all effects were statistically significant. After we added childhood SES in Model II, the effect of childhood hunger was attenuated and became statistically insignificant among men. Among women, the associations between markers of childhood nutritional deprivation and cognitive impairment were robust in all models.

In additional analyses, we also estimated models with arm length/knee height as continuous variables (results not shown). After we controlled for all of the covariates, shorter arm length was significantly associated with higher odds of cognitive impairment for both men and women; shorter knee height was significantly associated with higher odds of cognitive impairment among

Table 2
Associations[a] of arm length with cognitive impairment among older Chinese adults: CLHLS, 2002.

	Men			Women		
	Model I	Model II	Model III	Model I	Model II	Model III
Childhood nutrition						
Arm length in lowest 10th percentile (vs. above lowest 10th percentile)	1.67 (1.33–2.10)**	1.68 (1.34–2.12)**	1.62 (1.27–2.08)**	1.47 (1.23–1.75)**	1.46 (1.23–1.74)**	1.38 (1.15–1.65)**
Went to bed hungry (vs. did not go to bed hungry)	1.29 (1.10–1.51)**	1.09 (0.92–1.29)	1.12 (0.94–1.34)	1.35 (1.20–1.51)**	1.27 (1.13–1.43)**	1.27 (1.12–1.43)**
Childhood SES						
Born in rural (vs. urban) area		1.14 (0.90–1.45)	1.10 (0.85–1.43)		1.00 (0.85–1.17)	0.96 (0.81–1.15)
Received 1–6 years of schooling (vs. 7+)		1.48 (1.12–1.96)**	1.59 (1.18–2.13)**		1.45 (0.94–2.23)	1.44 (0.92–0.223)
Received 0 years of schooling (vs. 7+)		2.51 (1.89–3.34)**	2.64 (1.94–3.59)**		2.04 (1.36–3.07)**	2.05 (1.36–3.11)**
Adulthood SES						
Living in rural (vs. urban) area			1.36 (1.13–1.64)**			1.18 (1.04–1.34)**
Manual occupation (vs. non-manual)			1.05 (0.86–1.29)			1.15 (0.97–1.35)
Other covariates						
Age	1.55 (1.28–1.88)**	1.56 (1.28–1.89)**	1.52 (1.24–1.86)**	1.86 (1.58–2.19)**	1.85 (1.57–2.18)**	1.67 (1.42–1.97)**
Age squared	0.998 (0.997–0.999)**	0.998 (0.997–0.999)**	0.998 (0.997–0.999)**	0.997 (0.996–0.998)**	0.997 (0.996–0.998)**	0.998 (0.997–0.999)**
Non-Han ethnicity (vs. Han)	0.88 (0.61–1.26)	0.82 (0.57–1.18)	0.99 (0.68–1.45)	0.71 (0.55–0.91)**	0.69 (0.54–0.89)**	0.85 (0.66–1.08)
Unmarried (vs. married)			1.33 (1.10–1.60)**			1.50 (1.13–1.99)**
Current smoker (vs. nonsmoker)			0.94 (0.78–1.14)			0.95 (0.76–1.20)
Having selected diseases (vs. no selected diseases)			1.23 (1.02–1.50)*			1.06 (0.92–1.22)
ADL disabled (vs. no ADL disability)			4.04 (3.41–4.79)***			3.09 (2.75–3.48)**
−log pseudolikelihood	2124.0	2089.2	1936.3	3926.4	3913.8	3717.9

*$p < 0.05$; **$p < 0.01$.
[a] Odds ratios (95% CI) from binary logistic models are reported.

women and marginally associated ($p < 0.1$) with higher odds of cognitive impairment among men.

Next, we examined the association between markers of early-life nutritional deprivation and the onset of cognitive impairment over the three-year follow-up among those elderly whose cognitive function was considered normal in 2002 (MMSE $\geq$ 18). Tables 4 and 5 summarize the results from a series of multinomial logistic regression models. Table 4 shows that men with arm lengths below the 10th percentile were 49% more likely to be cognitively impaired than others at follow-up, controlling for age, age squared and ethnicity. The effect remained robust after controlling for childhood SES, adulthood SES and other covariates. Going to bed hungry was associated with 37% higher odds of experiencing cognitive impairment during the follow-up for older men, controlling for age, age squared, and ethnicity, and the effect was reduced and became statistically insignificant when childhood SES was added. However, among older women, the associations between markers of early childhood nutritional deprivation and cognitive impairment were not statistically significant. Again, we re-estimated all of the models in Table 4, substituting knee height for arm length (see Table 5). After we controlled for all of the covariates, the effects of knee height and childhood hunger were in the expected direction but not statistically significant for both men and women.

In an additional analysis, we also tested whether the effect of childhood nutritional status varied by age. We included interaction terms of age with arm length and going to bed hungry in the full models of Tables 2 and 4 (interaction terms of age with knee height and going to bed hungry were added in Tables 3 and 5). None of the interaction terms were statistically significant.

Discussion

Consistent with the growing literature on the relationship between early-life conditions and cognitive functioning in later life in developed and developing countries, we found that among both men and women, childhood nutritional deprivation was significantly associated with the odds of cognitive impairment in old age at baseline, supporting our first hypothesis. We also found some evidence supporting our second hypothesis. At baseline, the parameter estimates for arm length and hunger were reduced when childhood socioeconomic conditions and adulthood conditions were added sequentially. In addition, examining the sensitivity of the estimates more closely, the decline in the effect of arm length was due to the addition of ADL limitations to the model; the decline in the effect of self-reported hunger occurred when education was controlled for (results available upon request).

A surprisingly robust finding in our study, for women in particular, is the effect of a relatively crude measure of adequate food intake in childhood. A simple question about whether the respondent frequently went to bed hungry as a child was significantly associated with the odds of cognitive impairment in old age for both men and women at baseline. This is an important finding that suggests that fighting hunger throughout childhood not only saves children's lives and improves their health but may also enhance cognitive well-being in late-life. Currently, there are 915 million hungry people in developing countries, according to latest statistics from the Food and Agriculture Organization (FAO), and 25% of these hungry people are children (United Nations World Food Programme, 2010). Across the globe, 178 million children under age 5 are stunted or short in stature due to hunger, infection, or both (United Nations World Food Programme, 2007), which suggests that as they enter old age, they may be at higher risk for cognitive problems.

As for the onset of cognitive impairment over a three-year follow-up, the results are mixed. Although arm length was

Table 3
Associations[a] of knee height with cognitive impairment among older Chinese adults: CLHLS, 2002.

	Men			Women		
	Model I	Model II	Model III	Model I	Model II	Model III
Childhood nutrition						
Knee height in lowest 10th percentile (vs. above lowest 10th percentile)	1.18 (0.93–1.49)	1.15 (0.91–1.46)	1.08 (0.84–1.39)	1.32 (1.12–1.56)**	1.31 (1.11–1.54)**	1.24 (1.04–1.48)*
Went to bed hungry (vs. did not go to bed hungry)	1.29 (1.10–1.51)**	1.09 (0.92–1.29)	1.12 (0.93–1.34)	1.35 (1.21–1.52)**	1.28 (1.14–1.43)**	1.27 (1.12–1.44)**
−log pseudolikelihood	2132.3	2098.1	1943.7	3930.4	3917.9	3720.9

*$p < 0.05$; **$p < 0.01$.
[a] Odds ratios (95% CI) from binary logistic models are reported. Model I was adjusted for age, age squared, and ethnicity; Model II added childhood SES; Model III was adjusted for all confounders in Model II as well as current residence, occupation before age 60, marital status, smoking status, chronic disease, and ADL limitations.

significantly associated with the odds of cognitive impairment among older men, such an association was not evident in older women. The gender difference is a bit surprising given that a recent study in the U.S. (Huang et al., 2008) documented that arm span is significantly associated with the onset of dementia for both men and women aged 65 and older. This may be partly due to the fact that the two studies focused on different age groups: in Huang et al.'s study, only 8% of the sampled older adults were aged 80 years and above; our study oversampled the oldest old, and about 70% of older adults in the sample were 80 years and older and thus had extremely high mortality rates. It is also possible that the effect of undernutrition on cognitive impairment onset in old age has already played out prior to the beginning of observation in our sample (as shown in the prevalence results), especially for women, who have higher incidence of cognitive impairment than men in late-life in China (Zhang, 2006). Huang et al. also included a longer

Table 4
Associations[a] of arm length with onset of cognitive impairment among older Chinese adults: CLHLS, 2002–2005.

	Men			Women		
	Model I	Model II	Model III	Model I	Model II	Model III
Childhood nutrition						
Arm length in lowest 10th percentile (vs. above lowest 10th percentile)	1.49 (1.07–2.07)*	1.47 (1.06–2.04)*	1.47 (1.06–2.05)*	0.84 (0.61–1.16)	0.83 (0.60–1.15)	0.83 (0.60–1.15)
Went to bed hungry (vs. did not go to bed hungry)	1.37 (1.09–1.73)**	1.22 (0.96–1.54)	1.22 (0.96–1.55)	1.15 (0.96–1.43)	1.08 (0.90–1.29)	1.09 (0.91–1.30)
Other childhood SES						
Born in rural (vs. urban) area		1.35 (0.96–1.91)	1.35 (0.95–1.94)		1.19 (0.92–1.54)	1.19 (0.90–1.57)
Received 1–6 years of schooling (vs. 7+)		1.27 (0.91–1.79)	1.28 (0.91–1.81)		0.94 (0.55–1.61)	0.94 (0.55–1.61)
Received 0 years of schooling (vs. 7+)		1.77 (1.23–2.54)**	1.77 (1.21–2.59)**		1.33 (0.81–2.18)	1.34 (0.81–2.21)
Adulthood SES						
Living in rural vs. (vs. urban) area			1.01 (0.78–1.29)			1.05 (0.87–1.28)
Manual occupation (vs. non-manual)			1.01 (0.77–1.33)			0.99 (0.77–1.26)
Other covariates						
Age	1.14 (0.94–1.37)	1.14 (0.94–1.38)	1.13 (0.94–1.37)	1.23 (1.07–1.43)**	1.23 (1.06–1.43)**	1.21 (1.04–1.41)*
Age squared	1.00 (0.999–1.001)	1.00 (0.999–1.001)	1.00 (0.999–1.001)	0.999 (0.999–1.000)	0.999 (0.999–1.000)	0.999 (0.999–1.000)
Non–Han ethnicity (vs. Han)	1.03 (0.65–1.64)	1.00 (0.63–1.60)	1.05 (0.65–1.67)	0.90 (0.65–1.26)	0.88 (0.63–1.22)	0.92 (0.66–1.29)
Unmarried (vs. married)			1.37 (1.08–1.74)**			1.23 (0.94–1.61)
Current smoker (vs. nonsmoker)			1.07 (0.85–1.35)			1.24 (0.91–1.68)
Having selected diseases (vs. no selected diseases)			1.30 (1.00–1.67)*			1.10 (0.89–1.35)
ADL disabled (vs. no ADL disability)			1.68 (1.25–2.25)**			1.62 (1.31–2.00)**
−log pseudolikelihood	5917.0	5876.3	5754.7	6879.7	6849.2	6747.7

*$p < 0.05$; **$p < 0.01$.
[a] Odds ratios (95% CI) from multinomial logistic models are reported. The odds of death vs. cognitively normal and the odds of loss to follow-up vs. cognitively normal are not reported.

Table 5
Associations[a] of knee height with onset of cognitive impairment among older Chinese adults: CLHLS, 2002–2005.

	Men			Women		
	Model I	Model II	Model III	Model I	Model II	Model III
Childhood nutrition						
Knee height in lowest 10th percentile (vs. above lowest 10th percentile)	1.15 (0.82–1.61)	1.13 (0.81–1.58)	1.13 (0.80–1.58)	1.13 (0.84–1.52)	1.12 (0.83–1.51)	1.14 (0.84–1.53)
Went to bed hungry (vs. did not go to bed hungry)	1.38 (1.10–1.73)**	1.22 (0.96–1.54)	1.22 (0.96–1.54)	1.15 (0.96–1.37)	1.08 (0.90–1.29)	1.09 (0.91–1.31)
−log pseudolikelihood	5920.7	5880.0	5758.8	6879.0	6848.7	6747.6

*$p < 0.05$; **$p < 0.01$.
[a] Odds ratios (95% CI) from multinomial logistic models are reported. Model I was adjusted for age, age squared, and ethnicity; Model II added childhood SES; Model III was adjusted for all confounders in Model II as well as current residence, occupation before age 60, marital status, smoking status, chronic disease, and ADL limitations. The odds of death vs. cognitively normal and the odds of loss to follow-up vs. cognitively normal are not reported.

follow-up than the present study did. Future research that includes more young elderly participants, an improved measure of childhood nutritional status, and a longer observation window is clearly needed to replicate these findings and shed more light on these intriguing associations.

We emphasize that our results may only pertain to this population or populations subject to similar conditions. A comparison with recent work in China by Heys et al. (2009) and Zhang et al. (2009) shows that although different proxies of early-life nutritional deprivation were used, the studies reached the same conclusion: Early-life nutrition is important for cognitive functioning in later life, and the effect is robust when adulthood factors are accounted for. However, a comparison of our results with those of Case and Paxson's (2008) recent study for the U.S. points to possible reasons why our results may be context specific. First and foremost, the Chinese population examined in this study experienced childhood nutritional deprivation on a scale unmatched in the United States. This may contribute to the fact that in our study, the effects of early-life nutrition are stable after controlling for various childhood and adulthood conditions, in contrast to Case and Paxson, who find that early-life nutrition is largely indirectly associated with cognitive impairment. Second, and related to the first point, the older Chinese population received substantially less education than the American population and was much less likely to work in occupations that offered cognitive challenges. These appear to be important pathways linking early-life nutrition with cognitive impairment in the American population but are much less so in the Chinese population. The key point is that the Chinese and American populations were subjected to radically different life-course exposures that influence cognitive function, which very likely contributes to the differences in the patterns of associations.

This study has several limitations. First, we do not have information about the respondents' health conditions in childhood, including exposure to various infectious diseases rampant in early 20th century China (Campbell, 1997). In a recent article, Crimmins and Finch (2006) suggested that height can also be influenced by infections and ensuing inflammation in addition to food intake. Therefore, part of the association between limb length and the risk of cognitive impairment may reflect the role of childhood infections and inflammation in addition to the role of undernutrition. The relative importance of childhood nutritional deficits versus childhood infections in increasing the risk of cognitive impairment deserves further research. Second, a brief epidemiological screening instrument (i.e., the MMSE) was used to detect cognitive impairment rather than a comprehensive clinical evaluation. Clinical evaluations are usually more accurate. In addition, because we used a global measure of cognitive functioning, we could not examine which dimensions of cognitive functioning/change are most sensitive to early-life undernutrition. Third, we relied on retrospective self-reports of childhood hunger as well as proxy reports for those who were unable to answer the question. Like other studies that use retrospective reports, there is the potential problem of recall bias, especially among those who are cognitively impaired. Fourth, like many published studies in this field, we did not have information about the cognitive abilities of our respondents in childhood or young adulthood and therefore cannot rule out the possibility that some of the older adults were cognitively impaired in childhood or young adulthood. This scenario, though, is very unlikely given that the majority of our respondents are over the age of 80 and previous research has shown that cognitive functioning is inversely associated with life expectancy (Deary, 2008). Nonetheless, we were able to examine the association between early-life nutritional status and cognitive decline over a period of three years, making a significant contribution to the current literature that relies overwhelmingly on cross-sectional data. The final caveat in interpreting the results is that our sample of the older Chinese is comprised of robust survivors of much political, economic, and social unrest occurring in 20th century China. We suspect that our estimates of the impact of nutritional deprivation may be conservative due to selective mortality because previous research in China has found that people with poor early-life SES were more likely to die than their advantaged counterparts (Zhu & Xie, 2007).

Despite these limitations, our study makes contributions to the current discussion about childhood conditions and late-life cognition by investigating this association with a population-based, random, longitudinal survey in China. Our childhood measures are an improvement over some previous studies that focused primarily on retrospective reports of parents' education and occupation. Our measures included both self-reported and measured indicators of nutritional deprivation in childhood. At the public health level, our findings suggest that policies and interventions that target hunger and malnutrition in developing countries might not only improve the health and survival of tens of thousands of children but ultimately may benefit the whole society many decades later in terms of reducing the burden of cognitive impairment of older adults.

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