Survival, disabilities in activities of daily living, and physical and cognitive functioning among the oldest-old in China: a cohort study

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Summary

Background The oldest-old (those aged ≥80 years) are the most rapidly growing age group globally, and are most in need of health care and assistance. We aimed to assess changes in mortality, disability in activities of daily living, and physical and cognitive functioning among oldest-old individuals between 1998 and 2008.

Methods We used data from the Chinese Longitudinal Healthy Longevity Study. Three pairs of cohorts aged 80–89 years, 90–99 years, and 100–105 years (in total, 19 528 oldest-old participants) were examined; the two cohorts in each pair were born 10 years apart, with the same age at the time of the assessment in the 1998 and 2008 surveys. Four health outcomes were investigated: annual death rate, Activities of Daily Living (ADL), physical performance in three tests and cognitive function measured by Mini-Mental State Examination (MMSE). We used different tests and multivariate regression analyses to examine the cohort differences.

Findings Controlling for various confounding factors, we noted that annual mortality among oldest-old individuals was substantially reduced between 0·2% and 1·3% in 1998–2008 compared with individuals of the same age born 10 years previously, and that disability according to activities of daily living had significantly reduced annually between 0·8% and 2·8%. However, cognitive impairment in the later cohorts increased annually between 0·7% and 2·2% and objective physical performance capacity (standing up from a chair, picking up a book from the floor, and turning around 360°) decreased anually between 0·4% and 3·8%. We also noted that female mortality was substantially lower than male mortality among the oldest-old, but that women's functional capacities in activities of daily living, cognition, and physical performance were worse than their male counterparts.

Interpretation Advances in medications, lifestyle, and socioeconomics might compress activities of daily living disability, that is, benefits of success, but lifespan extension might expand disability of physical and cognitive functioning as more frail, elderly individuals survive with health problems, that is, costs of success.

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Introduction

Population aging is one of the major challenges facing most countries in the world, including China. The accompanied dramatic increase in numbers of the oldest-old (individuals older than 80 years) is of particular concern, presenting a major challenge for health and social care systems, because the oldest-old often need daily assistance and medical care.[1] Two contrasting scenarios of health trends in aging populations have been proposed. One view states that advances in medical technology, improvements in lifestyle, and socioeconomic development will postpone the onset of disability and chronic diseases among the elderly, so that morbidity will be compressed in old age.[2–4] This concept is linked to the benefits of success—ie, that people are living longer (success) and in better health at older ages than they were previously (benefits). By contrast, in the alternative scenario, reduced mortality is hypothesised to result in an increased number of frail elderly people surviving with health problems, thus worsening the overall health of the elderly population. This concept is often referred to as expansion of morbidity,[5,6] closely linked to that of costs of success, which specifically means that people's lifespans are lengthening (success) but with worse health at older ages than previously (costs). In reality, these two trends might coexist and interplay,[7] and the concept of dynamic equilibrium has been introduced to help understand the association between morbidity and increasing life expectancy.[8]

Trends in the overall health status of the elderly population are generally positive in high-income societies.[9] However, several reports support the opposite trend for some major health indicators. For example, findings from a Swedish study showed that the objective function tests of physical capacity, lung function, and cognition were significantly worse in 2002 compared with 1992 in individuals older than 77 years.[10] Although dementia incidence has fallen in some European countries[11] and the USA,[12] findings from nine large Japanese studies[13] have suggested that prevalence of all-cause dementia and Alzheimer's disease are increasing in Japan. Investigators building on the work of several

For the **Wan Fan database search engine** see http://www.wanfangdata.com.cn/

For the **Knowledge Network search engine** see http://www.cnki.net/

Research in context

Evidence before this study

We used PubMed, Web of Science, and Google Scholar to search for publications before Aug 30, 2016 in English. The Chinese literature was identified through searches of the Wan Fan database search engine and the Knowledge Network search engine. We used the search terms "oldest-old", "old age", "mortality", "ADL", "cognitive function", "physical performance", and "cohort differences", etc. We also checked the reference lists of the related publications identified in the search. Existing scientific literature has provided empirical support for both compression of morbidity (including disability and chronic diseases) and expansion of morbidity as human longevity increases. However, no research so far has investigated the mixed effects of these two opposing trends in a single study with a large enough sample size of the oldest-old cohorts, except one study of Danish cohorts.

Added value of this study

Our findings support that, with increased longevity (success), there are co-existence and mixed effects of compression of disability in activities of daily living (benefits of success) and expansion of disability in physical and cognitive functioning (costs of success), which is in general consistent with findings from the Danish study that compared one pair of cohorts born 10 years apart aged 93 or 95 years in 1998 or 2010, with a total sample size of 5430 nonagenarians. However, we also noted important differences. The novelty of this study is that we compare three groups of Chinese cohorts born 10 years apart aged 80–89 years, 90–99 years, and 100–105 years at the time of the surveys in 1998 or 2008, with a total sample of 19 528 oldest-old participants. To our knowledge, this study is the first investigation of this important issue based on the largest dataset of oldest-old cohorts in the world and from a low-income or middle-income country.

Implications of all the available evidence

The combination of declining mortality with worsening cognition and physical performance among the rapidly growing population of oldest-old individuals has clear policy implications for health systems and social care, not only in China but also globally. Many more state-subsidised public and private programmes and enterprises are urgently needed to provide services to meet the various needs of the rapidly growing elderly population, especially the oldest-old. Additionally, programmes to prevent chronic disease in elderly people through individualised health interventions need to be prioritised.

studies (including two nationally representative surveys) reported opposing trends of improvement in disability measures, alongside an expansion of morbidity in chronic diseases and functional impairments, among Swedish oldest-old.[10,14]

Several studies have reported that the prevalence of disability according to activities of daily living among Chinese elderly people has decreased in the past two decades.[15,16] However, Wu and colleagues[17] concluded that dementia prevalence among elderly individuals aged 70 years or older was generally increasing, on the basis of an evaluation of 70 prevalence studies of dementia in mainland China, Hong Kong, and Taiwan from 1980 to 2012.[17] Similarly, Chan and colleagues[18] reported that the prevalence of all forms of dementia at ages 65–69 years and 95–99 years in China in 2010 had increased by 44·4% and 43·7%, respectively, compared with 1990.[18]

The existing scientific literature provides empirical support for both compression and expansion of morbidity, but little research so far has investigated the mixed effects of these two opposing trends in a single study with a sufficient sample size of the oldest-old. The exception is a Danish study of a cohort born in 1905 and assessed at age 93 in 1998, compared with a later cohort born in 1915 and assessed at age 95 in 2010.[19] This study provided some support for the mixed effects of both compression of morbidity and expansion of morbidity. However, whether these mixed effects also exist among the oldest-old in low-income or middle-income countries such as China is unclear. We aimed to address this research question by comparatively analysing cohorts of the oldest-old born in 1909–18 versus 1919–28 (aged 80–89 years in 1998 *vs* 2008), born in 1899–1908 versus 1909–18 (aged 90–99 years in 1998 *vs* 2008), and born in 1893–98 versus 1903–08 (aged 100–105 years in 1998 *vs* 2008). To our knowledge, this study is the first to assess this important issue in a low-income or middle-income country, and uses the largest dataset of oldest-old cohorts in the world.

Methods

Study design and participants

This study draws on data from the oldest-old participants (ie, those aged 80–105 years) from the 1998 and 2008 waves of the Chinese Longitudinal Healthy Longevity Surveys (CLHLS). The CLHLS is a nationwide survey done in a randomly selected half of the counties and cities in 22 of the 31 provinces, covering about 85% of the total population of China. The CLHLS attempted to interview all centenarians who voluntarily agreed to participate in the study in the sampled counties and cities. The CLHLS also adopted a targeted random-sample design to ensure representativeness, through interviews with approximately equal numbers of male and female nonagenarians, octogenarians, and young-old (aged 65–79 years) living near to the centenarians (ie, in the same village or street, if available, or in the same sampled county or city). This design serves well our aim of investigating determinants of healthy longevity of different age and sex groups who live in the same social and natural environment.[20]

The Research Ethics Committees of Peking University and Duke University granted approval for the Protection of Human Subjects for the Chinese Longitudinal Healthy Longevity Survey, including collection of the data used for present study. The survey respondents gave informed consent before participation.

Procedures

The CLHLS was initially designed to facilitate international comparative analyses, and its questionnaire was translated from the instruments of the Danish longevity survey analysed by Christensen and colleagues.[19] The instruments were adapted to the Chinese culture and socioeconomic context. A wide variety of international and domestic studies have confirmed that age reporting of the Han Chinese oldest-old is in general reasonably accurate, due to the cultural tradition of memorising one's date of birth to determine dates of important life events such as engagement and marriage.[21,22]

The CLHLS 1998 and 2008 surveys used almost exactly the same ascertainment and assessment protocols. No proxy was used for objective questions such as assessment of cognitive function and physical performance. The survey was administered in the participants' homes by trained interviewers from the local centres for disease prevention and control for university students. More details about CLHLS, including sampling design, follow-up interviews with surviving participants and deceased participants' close family members, data quality, and the variables analysed are described in the appendix.

Statistical analyses

We divided individuals into oldest-old born in 1909–18 versus 1919–28 (aged 80–89 years in 1998 *vs* 2008), born in 1899–1908 versus 1909–18 (aged 90–99 years in 1998–2008), and born in 1893–98 versus 1903–08 (aged 100–105 years in 1998 *vs* 2008).

We compared annual mortality, self-reported disability according to the activities of daily living scale, physical performance in three tests, and cognitive function measured by Mini Mental State Examination scores for men and women separately and for both sexes combined. We did standard statistical χ^2 tests (one-sided) or Z tests (two-sided) for categorical data, and t tests (two-sided) for continuous data. We also did multivariate regression analyses to explore the changes in mortality, physical function, and cognitive function between the oldest-old cohorts born 10 years apart, adjusted for the covariates of age, rural or urban residence, marital status, and education, which are the major demographic and socioeconomic factors affecting the mortality and health of elderly people in China. We based the mortality analysis on parametric survival models with Weibull distribution, while the Weibull assumption was satisfied. All other analyses were based on logistic regression models or linear regression models. We used STATA version 13.1 for the statistical analyses.

Role of funding source

The study funders provided financial support for data collection and analysis, but had no role in the writing of the report, interpretation of the results, or submission for consideration of publication. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

We included 19 528 individuals in our study, comprising 7288 octogenarians, 7234 nonagenarians, and 5006 centenarians, interviewed in 1998 and 2008 (in view of the very high mortality at advanced ages, only 2·8% of the oldest-old participants were interviewed in both 1998 and 2008 surveys). The appendix presents the basic demographic characteristics of the cohorts. Tables 1–3 present the detailed results of cross-cohort changes in physical and cognitive function and death during follow-up for men, women, and both sexes combined. Figures 1, 2 and table 4 present the summary results.

Age-specific and sex-specific mortality among Chinese oldest-old aged 80–89 years, 90–99 years, and 100–105 years were all reduced in the later cohorts compared with the cohorts born 10 years earlier (figure 1; tables 1–3). All of the nine sets of comparisons of age-specific mortality between the different cohorts of the oldest-old showed reductions of –0·2% to –1·3% in annual mortality during follow-up (table 4). Adjusted for covariates of age, sex, education, and rural or urban residence, the cross-cohort reduction in age-specific and sex-specific mortality was statistically significant in sex-combined centenarians (p=0·0032) and female centenarians (p=0·0163), and not significant in sex-combined octogenarians and nonagenarians, male or female octogenarians, male or female nonagenarians, or male centenarians (tables 1–3).

See Online for appendix

Disability as measured through activities of daily living of the Chinese oldest-old was significantly reduced in the later cohorts compared with the earlier cohorts (figure 1, tables 1–3). All of the nine sets of comparisons between different cohorts of the oldest-old showed substantial reductions in annual rates of disability, ranging from –0·8% to –2·8% (table 4). Adjusted for the covariates, the cross-cohort reductions in the mean score of activities of daily living disability were statistically significant (p<0·0001) for nonagenarians and centenarians (both sexes combined) and female nonagenarians and centenarians, significant (ranging from p=0·0023 to p=0·0082) in sex-combined octogenarians and male nonagenarians, significant (ranging from p=0·0257 to p=0·0290) in female and

	Both sexes combined				Men				Women				Sex difference	
	Years of birth		p value of change		Years of birth		p value of change		Years of birth		p value of change		p value (adjusted)	
	1909–18 (n=3235)	1919–28 (n=4053)	Un-adjusted	Adjusted*	1909–18 (n=1641)	1919–28 (n=2030)	Un-adjusted	Adjusted*	1909–18 (n=1594)	1919–28 (n=2023)	Un-adjusted	Adjusted*	1909–18 (n=3235)	1919–28 (n=4053)
Age, years	83·07 (2·59)	82·98 (2·57)	0·1516†	0·2493	82·87 (2·51)	82·81 (2·50)	0·4955†	0·3279	83·20 (2·64)	83·11 (2·61)	0·3055†	0·5796	··	··
Annual death rate	10·3%	9·6%	0·3204‡	0·0599	12·5%	10·9%	0·1325‡	0·0671	9·0%	8·7%	0·7523‡	0·2640	<0·0001	<0·0001
Mean ADL disability score (range 0–6)	0·36 (1·06)	0·28 (1·01)	0·0006†	0·0023	0·32 (1·01)	0·24 (0·93)	0·0219†	0·029	0·39 (1·08)	0·30 (1·06)	0·0163†	0·026	0·012	0·083
Missing	18 (0·6%)	1 (<0·1%)	··	··	10 (0·6%)	1 (<0·1%)	··	··	8 (0·5%)	0	··	··	··	··
0–1	2974 (92·4%)	3823 (94·4%)	··	··	1525 (93·5%)	1927 (95·0%)	··	··	1456 (91·8%)	1899 (93·9%)	··	··	··	··
2	80 (2·5%)	51 (1·3%)	··	··	33 (2·0%)	28 (1·4%)	··	··	44 (2·8%)	23 (1·2%)	··	··	··	··
≥3	164 (5·1%)	178 (4·4%)	··	··	73 (4·5%)	73 (3·6%)	··	··	86 (5·5%)	100 (5·0%)	··	··	··	··
p value	··	··	0·0015‡	0·0054	··	··	0·2077‡	0·0708	··	··	0·0055‡	0·0293	0·0425	0·0933
Mean physical performance score (range 0–1)														
Stand-up from chair	0·92 (0·21)	0·86 (0·28)	<0·0001†	<0·0001	0·93 (0·20)	0·87 (0·26)	<0·0001†	<0·0001	0·92 (0·22)	0·84 (0·29)	<0·0001†	<0·0001	0·1538	0·3616
Missing	15 (0·5%)	1 (<0·1%)	··	··	9 (0·6%)	0	··	··	6 (0·4%)	1 (0·1%)	··	··	··	··
Pick-up a book from floor	0·90 (0·25)	0·85 (0·29)	<0·0001†	<0·0001	0·91 (0·23)	0·87 (0·27)	<0·0001†	<0·0001	0·89 (0·26)	0·84 (0·29)	<0·0001†	<0·0001	0·0483	0·0566
Missing	18 (0·6%)	0	··	··	14 (0·8%)	0	··	··	6 (0·4%)	0	··	··	··	··
Turn-around 360°	0·91 (0·28)	0·81 (0·39)	<0·0001†	<0·0001	0·92 (0·27)	0·84 (0·37)	<0·0001†	<0·0001	0·91 (0·29)	0·79 (0·41)	<0·0001†	<0·0001	0·9276	0·0172
Missing	11 (0·3%)	1 (<0·1%)	··	··	10 (0·6%)	0	··	··	2 (0·1%)	1 (<0·1%)	··	··	··	··
Mean MMSE score (range 0–30)	24·82 (5·37)	22·87 (7·27)	<0·0001†	<0·0001	25·86 (5·09)	24·18 (6·32)	<0·0001†	<0·0001	24·17 (5·44)	21·93 (7·56)	<0·0001†	<0·0001	<0·0001	<0·0001
Missing	26 (0·8%)	9 (0·2%)	··	··	13 (0·8%)	4 (0·2%)	··	··	12 (0·8%)	5 (0·3%)	··	··	··	··
0–17	285 (8·9%)	658 (16·3%)	··	··	97 (6·0%)	206 (10·2%)	··	··	169 (10·7%)	416 (20·7%)	··	··	··	··
18–22	437 (13·6%)	744 (18·4%)	··	··	148 (9·1%)	308 (15·2%)	··	··	260 (16·4%)	418 (20·7%)	··	··	··	··
23–27	1328 (41·4%)	1439 (35·6%)	··	··	642 (39·5%)	791 (39·0%)	··	··	674 (42·6%)	668 (33·2%)	··	··	··	··
28–30	1157 (36·1%)	1200 (29·7%)	··	··	737 (45·4%)	722 (35·6%)	··	··	479 (30·3%)	513 (25·5%)	··	··	··	··
p value	··	··	<0·0001‡	<0·0001	··	··	<0·0001‡	<0·0001	··	··	<0·0001‡	<0·0001	<0·0001	<0·0001

Data are mean (SD) or n (%). The mean annual death rates, mean ADL disability scores, mean physical performance scores and mean MMSE scores are weighted averages using age-sex-residence (rural or urban)-specific sample weights as described in the appendix. Tests for annual death rates are based on parametric survival model with Weibull distribution; all other tests are based on logistic regression models or linear regression models. ADL=activities of daily living. MMSE=Mini-Mental State Examination. *Multivariate model tests of the difference between the cohorts of men or women are adjusted for age, education, rural or urban residence, and marital status; in the tests for "Both sexes combined", gender is also adjusted for. †Test of equal mean. ‡Test of equal proportions.

Table 1: **Mortality, disability in ADL, and cognitive and physical function for cohorts born in 1909–18 (aged 80–89 years in 1998) and born in 1919–28 (aged 80–89 years in 2008)**

	Both sexes combined				Men				Women				Sex difference	
	Years of birth		p value of change		Years of birth		p value of change		Years of birth		p value of changes		p value (adjusted)	
	1899–1908 (n=2896)	1909–18 (n=4338)	Un-adjusted	Adjusted*	1899–1908 (n=1243)	1909–18 (n=1810)	Un-adjusted	Adjusted*	1899–1908 (n=1653)	1909–18 (n=2528)	Un-adjusted	Adjusted*	1899–1908 (n=2896)	1909–18 (n=4338)
Age, years	92·11 (2·13)	92·24 (2·19)	0·0109†	0·0195	92·00 (2·11)	91·99 (1·99)	0·9104†	0·8287	92·15 (2·14)	92·33 (2·25)	0·0078†	0·0065	..	..
Annual death rate	24·1%	23·4%	0·4926‡	0·0647	27·1%	25·6%	0·3545‡	0·1178	23·0%	22·6%	0·7629‡	0·1859	0·0006	<0·0001
Mean ADL disability score (range 0–6)	0·94 (1·62)	0·74 (1·55)	<0·0001†	<0·0001	0·74 (1·49)	0·59 (1·42)	0·0054†	0·0082	1·02 (1·66)	0·80 (1·59)	<0·0001†	<0·0001	0·0022	0·0094
Missing	10 (0·3%)	0	..	..	5 (0·4%)	0	..	..	5 (0·3%)	0	..	..	..	..
0–1	2290 (79·4%)	3618 (83·4%)	..	..	1031 (83·3%)	1578 (87·2%)	..	..	1283 (77·9%)	2073 (82·0%)	..	..	..	..
2	152 (5·3%)	181 (4·2%)	..	..	59 (4·8%)	57 (3·2%)	..	..	90 (5·5%)	115 (4·6%)	..	..	..	..
≥3	443 (15·4%)	538 (12·4%)	..	..	148 (11·9%)	175 (9·7%)	..	..	275 (16·7%)	340 (13·5%)	..	..	..	..
p value	..	..	0·0023‡	0·0001	..	..	0·0238‡	0·0078	..	..	0·0236‡	0·0024	0·0148	0·0072
Mean physical performance score (range 0–1)														
Stand-up from chair	0·80 (0·31)	0·72 (0·34)	<0·0001†	<0·0001	0·84 (0·28)	0·77 (0·32)	<0·0001†	<0·0001	0·78 (0·32)	0·71 (0·34)	<0·0001†	<0·0001	<0·0001	<0·0001
Missing	24 (0·8%)	10 (0·2%)			10 (0·8%)	7 (0·4%)			14 (0·8%)	4 (0·2%)				
Pick-up a book from floor	0·77 (0·33)	0·67 (0·37)	<0·0001†	<0·0001	0·83 (0·30)	0·74 (0·35)	<0·0001†	<0·0001	0·75 (0·34)	0·65 (0·38)	<0·0001†	<0·0001	<0·0001	<0·0001
Missing	28 (1·0%)	3 (0·1%)			13 (1·1%)	2 (0·1%)			16 (1·0%)	1 (0·1%)				
Turn-around 360°	0·78 (0·41)	0·59 (0·49)	<0·0001†	<0·0001	0·83 (0·38)	0·65 (0·48)	<0·0001†	<0·0001	0·76 (0·43)	0·57 (0·50)	<0·0001†	<0·0001	0·0019	<0·0001
Missing	21 (0·7%)	2 (0·1%)	..	..	7 (0·6%)	1 (<0·1%)	..	..	13 (0·8%)	2 (0·1%)	..	..	..	..
Mean MMSE score (range 0–30)	20·62 (7·93)	17·41 (9·62)	<0·0001†	<0·0001	22·95 (7·18)	19·81 (9·26)	<0·0001†	<0·0001	19·73 (8·02)	16·50 (9·59)	<0·0001†	<0·0001	<0·0001	<0·0001
Missing	39 (1·3%)	20 (0·5%)	..	..	16 (1·3%)	4 (0·2%)	..	..	23 (1·4%)	14 (0·6%)	..	..	..	..
0–17	789 (27·6%)	1778 (41·2%)	..	..	206 (16·7%)	538 (29·8%)	..	..	516 (31·7%)	1145(45·5%)	..	..	..	..
18–22	577 (20·2%)	936 (21·7%)	..	..	173 (14·1%)	366 (20·3%)	..	..	367 (22·6%)	559 (22·2%)	..	..	..	..
23–27	952 (33·4%)	1004 (23·2%)	..	..	519 (42·2%)	530 (29·4%)	..	..	487 (30·0%)	526 (20·9%)	..	..	..	..
28–30	537 (18·8%)	603 (14·0%)	..	..	332 (27·0%)	371 (20·6%)	..	..	255 (15·7%)	288 (11·4%)	..	..	..	..
p value	..	..	<0·0001‡	<0·0001	..	..	<0·0001‡	<0·0001	..	..	<0·0001‡	<0·0001	<0·0001	<0·0001

Data are mean (SD) or n (%). The mean annual death rates, mean ADL disability scores, mean physical performance scores and mean MMSE scores are weighted averages using age-sex-residence (rural or urban)-specific sample weights as described in the appendix. Tests for annual death rates are based on parametric survival model with Weibull distribution; all other tests are based on logistic regression models or linear regression models. ADL=activities of daily living. MMSE=Mini-Mental State Examination. *Multivariate model tests of the difference between the cohorts of men or women are adjusted for age, education, rural or urban residence, and marital status; in the tests for "Both sexes combined", gender is also adjusted for. †Test of equal mean. ‡Test of equal proportions.

Table 2: **Mortality, disability in ADL, and cognitive and physical functions for cohorts born in 1899–1908 (aged 90–99 years in 1998) and born in 1909–18 (aged 90–99 years in 2008)**

	Both sexes combined				Men				Women				Sex difference	
	Years of birth		p value of changes		Years of birth		p value of changes		Years of birth		p value of changes		p value (adjusted)	
	1893–98 (n=2197)	1903–08 (n=2809)	Un-adjusted	Adjusted*	1893–98 (n=439)	1903–08 (n=600)	Un-adjusted	Adjusted*	1893–98 (n=1758)	1903–08 (n=2209)	Un-adjusted	Adjusted*	1893–98 (n=2197)	1903–08 (n=2809)
Age, years	101·15 (1·34)	101·72 (1·55)	<0·0001†	<0·0001	101·03 (1·34)	101·52 (1·43)	<0·0001†	<0·0001	101·18 (1·34)	101·77 (1·58)	<0·0001†	<0·0001	..	..
Annual death rate	40·7%	38·0%	0·0521‡	0·0032	45·7%	41·2%	0·1479‡	0·0557	39·1%	37·4%	0·2735‡	0·0163	<0·0001	0·0253
Mean ADL disability score (range 0–6)	2·01 (2·09)	1·58 (2·00)	<0·0001†	<0·0001	1·57 (1·91)	1·45 (1·97)	0·3043†	0·0604	2·15 (2·12)	1·61 (2·00)	<0·0001†	<0·0001	<0·0001	0·0531
Missing	10 (0·5%)	0	..	..	1 (0·3%)	0	..	..	9 (0·5%)	0	..	..	..	..
0–1	1186 (54·2%)	1820 (64·8%)	..	..	274 (62·6%)	424 (70·7%)	..	..	899 (51·4%)	1399 (63·3%)	..	..	..	..
2	219 (10·0%)	229 (8·2%)	..	..	43 (9·7%)	38 (6·4%)	..	..	176 (10·1%)	190 (8·6%)	..	..	..	..
≥3	784 (35·8%)	759 (27·0%)	..	..	121 (27·6%)	137 (22·9%)	..	..	674 (38·5%)	620 (28·1%)	..	..	..	..
p value	..	..	<0·0001‡	<0·0001	..	..	0·0204‡	0·0024	..	..	<0·0001‡	<0·0001	<0·0001	0·0007
Mean physical performance score (range 0–1)														
Stand-up from chair	0·62 (0·37)	0·57 (0·37)	<0·0001†	0·0012	0·70 (0·36)	0·63 (0·37)	0·0017†	0·0064	0·59 (0·37)	0·56 (0·37)	0·0021†	0·0184	<0·0001	0·0050
Missing	36 (1·7%)	12 (0·4%)	..	..	8 (1·9%)	0	..	..	27 (1·6%)	12 (0·5%)	..	..	..	..
Pick-up a book from floor	0·56 (0·39)	0·49 (0·40)	<0·0001†	<0·0001	0·66 (0·38)	0·57 (0·41)	0·0002†	0·0061	0·52 (0·39)	0·47 (0·39)	<0·0001†	0·0004	<0·0001	<0·0001
Missing	51 (2·3%)	7 (0·3%)	..	..	12 (2·7%)	0	..	..	39 (2·2%)	7 (0·3%)	..	..	..	..
Turn-around 360°	0·52 (0·50)	0·37 (0·48)	<0·0001†	<0·0001	0·67 (0·47)	0·45 (0·50)	<0·0001†	<0·0001	0·47 (0·50)	0·35 (0·48)	<0·0001†	<0·0001	<0·0001	<0·0001
Missing	12 (0·6%)	2 (0·1%)	..	..	4 (1·0%)	0	..	..	8 (0·4%)	1 (0·1%)	..	..	..	..
Mean MMSE score (range 0–30)	14·63 (9·44)	11·63 (10·12)	<0·0001†	<0·0001	17·92 (9·19)	14·95(10·45)	<0·0001†	<0·0001	13·54 (9·27)	10·82 (9·87)	<0·0001†	<0·0001	<0·0001	<0·0001
Missing	44 (2·0%)	55 (2·0%)	..	..	9 (2·0%)	18 (3·1%)	..	..	35 (2·0%)	37 (1·7%)	..	..	..	..
0–17	1192 (55·3%)	1837 (66·5%)	..	..	172 (40·0%)	300 (51·2%)	..	..	1040 (60·3%)	1528 (70·2%)	..	..	..	..
18–22	420 (19·5%)	378 (13·7%)	..	..	89 (20·6%)	87 (14·9%)	..	..	330 (19·1%)	291 (13·4%)	..	..	..	..
23–27	386 (17·9%)	380 (13·8%)	..	..	107 (24·8%)	137 (23·5%)	..	..	270 (15·6%)	248 (11·4%)	..	..	..	..
28–30	158 (7·3%)	168 (6·1%)	..	..	63 (14·6%)	60 (10·3%)	..	..	85 (4·9%)	109 (5·0%)	..	..	..	..
p value	..	..	<0·0001‡	<0·0001	..	..	0·0022‡	0·0004	..	..	<0·0001‡	<0·0001	<0·0001	<0·0001

Percentages and numbers are mean (SD) or n (%). The mean annual death rates, mean ADL disability scores, mean physical performance scores and mean MMSE scores are weighted averages using age-sex-residence (rural or urban)-specific sample weights as described in the appendix. Tests for annual death rates are based on parametric survival model with Weibull distribution; all other tests are based on logistic regression models or linear regression models. ADL=activities of daily living. MMSE=Mini-Mental State Examination. *Multivariate model tests of the difference between the cohorts of men or women are adjusted for age, education, rural or urban residence, and marital status; in the tests for "Both sexes combined", gender is also adjusted for. †Test of equal mean. ‡Test of equal proportions.

Table 3: **Mortality, disability in ADL, and cognitive and physical function between cohorts born in 1893–98 (aged 100–105 years in 1998) and born in 1903–08 (aged 100–105 years in 2008)**

male octogenarians, and not significant in male centenarians (p=0·0604; tables 1–3).

The scores in objective physical performance tests (standing up from a chair, picking up a book from the floor, and turning-around 360° among the Chinese oldest-old were all significantly worsened in the later cohorts compared with the earlier cohorts (figure 2, tables 1–3). All of the 27 sets of comparisons of physical performance tests between different cohorts of the oldest-old showed substantial reductions in annual rates, from –0·4% to –3·8% (table 4). Adjusted for the covariates, the cross-cohort differences in objective physical performance were highly significant in octogenarians, nonagenarians, and centenarians for men, women, and both sexes combined (p<0·0001) in 22 comparisons, ranging from p=0·0004 to p=0·0064 in four comparisons, and p=0·0184 in one comparison; tables 1–3).

The cognitive function measured by the Mini Mental State Examination test scores of the Chinese oldest-old was significantly worse in the later cohorts compared with the earlier cohorts (figure 2, tables 1–3). All of the nine sets of comparisons of cognitive function between different cohorts of the oldest-old showed significant reductions in annual rates, ranging from –0·7% to –2·2% (table 4). Adjusted for the covariates, the cross-cohort differences in cognitive functional scores were statistically significant (p<0·0001) in all of the nine comparisons for octogenarians, nonagenarians, and centenarians, for both sexes and for men and women separately (tables 1–3).

Tables 1–3 show male–female comparisons of the six pairs of oldest-old cohorts aged 80–89 years, 90–99 years, and 100–105 years in 1998 and 2008; men had substantially and consistently higher age-specific mortality than did women, but substantially better health status in terms of ADL disability, physical performance test scores, and cognitive function. The sex differences in the 48 male–female comparisons were statistically significant (mostly p<0·001), except six non-significant comparisons in octogenarians and one non-significant comparison in centenarians.

Self-reported life satisfaction and self-reported good health significantly declined among the later oldest-old cohorts compared with the earlier oldest-old cohorts (appendix; p<0·0001), except self-reported health in centenarians. Of note, the period cross-sectional comparisons showed that average self-reported life satisfaction and health slightly increased or remained almost the same from ages 80–89 years to 90–99 years and 100 years or older in both the 1998 and 2008 surveys (appendix), whereas scores for disability as measured by activities of daily living, cognitive function, and physical performance were all largely increased with increased age (appendix).

Discussion

In this cohort study we compared three groups of Chinese individuals born 10 years apart, aged 80–89 years, 90–99 years, or 100–105 years at the time of surveys done in 1998 or 2008. To our knowledge, this study is the first to assess this important issue in a low-income or middle-income country, and uses the largest dataset of oldest-old cohorts in the world. Our findings are generally consistent with those from the Danish study that compared a pair of cohorts born 10 years apart and aged 93 or 95 in 1998 or 2010.[19] However, we also noted important differences.

Findings from both our Chinese study and the Danish study showed that mortality and disability (as defined by activities of daily living) among the later cohorts of the oldest-old were substantially reduced compared with the cohorts born 10 years earlier. However, the objective scores for physical performance (standing up from a

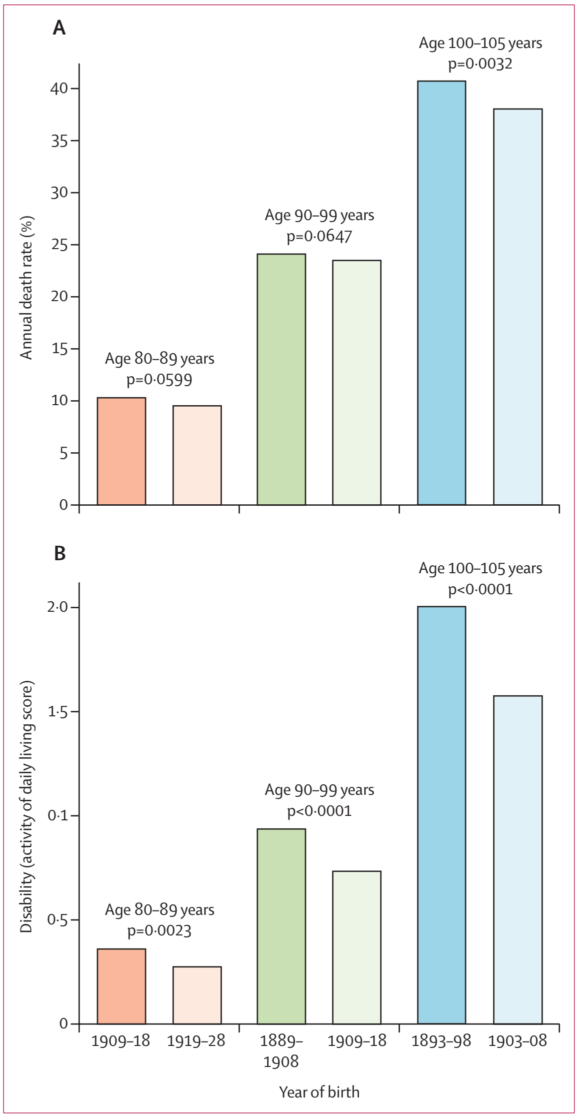

Figure 1: **Annual death rates and disability in activities of daily living compared within three pairs of cohorts**
Figure shows data for both sexes combined.

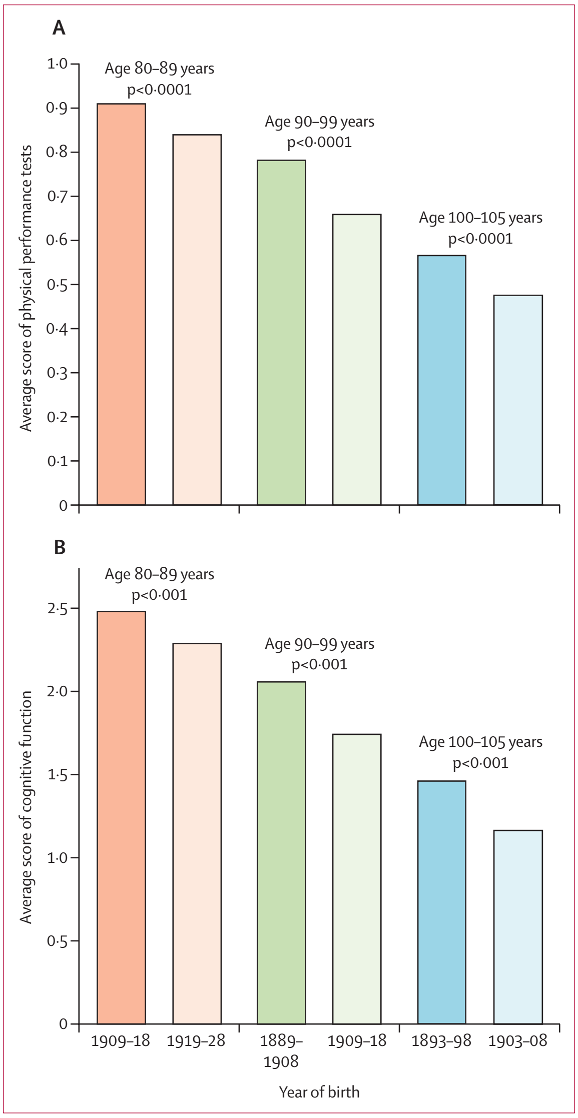

***Figure 2:* Objective physical performance tests and cognitive function compared within the three cohorts**
Figure shows data for both sexes combined.

chair, picking up a book from the floor, and turning around 360°) for the Chinese oldest-old were all significantly worse in the later cohorts compared with the earlier cohorts. This observation is mostly consistent with the general pattern in the Danish study. Compared with the earlier cohort, the Danish later cohort had substantially worse ability to stand up from a chair or walk for 3 m among women and for both sexes combined.[19]

Both this study and the Danish study showed apparently contradictory findings with respect to survival and self-reported activities of daily living versus objective physical performance tests. We believe that two underlying factors might help to understand this effect. The first is the mixed effects of the two opposing processes of compression of morbidity (ie, benefits of success) and expansion of morbidity (ie, costs of success). On one hand, the later cohorts might benefit from progress in effective disease treatment, healthier lifestyles, declining disability effects of some major chronic diseases (eg, stroke and cardiometabolic disease),[15] and improved standards of living due to rapid socioeconomic development in China. These benefits of success imply that the later cohorts of oldest-old individuals show reduced mortality due to postponement of senescence, and have reached older ages with improved health and functional capacity in daily living.[4] On the other hand, as compared with the earlier cohort, the later cohort includes more members who have survived life-threatening conditions (because of improvements in medical care and increased longevity), but they might be in relatively poor health, implying that the saving of lives might reduce overall physical functional capacity and health.[19] We propose to use the term “costs of success” to describe this effect.

The second underlying factor is associated with different types of disability measurements. Disability as measured by self-reported activities of daily living depends not only on health status, but also on facilities to assist such activities (eg, transferring, using the toilet, and bathing). The substantial improvement of activities of daily living among the Chinese oldest-old could be partly due to the rapid changes in living standards and availability of facilities for daily life during the past few decades in China. For example, average annual disposable income among urban and rural households in 2008 was 3·0 times higher (urban) and 2·2 times higher (rural) than in 1998.[23] Such rapid improvements in living standards that provide better facilities for daily life could help to explain the significant decreases in disability associated with activities of daily living. However, the objective tests of physical performance do not depend on facilities. Furthermore, self-reported activities of daily living are subject to substantially higher measurement errors compared with objectively-tested cognitive function and physical performance.[24] Thus, disability scores based on self-reported activities of daily living might not be an accurate indicator of physical health status, although it can be used as a good measurement of assistance needs in daily living activities. The objective tests of physical performance have added predictive value beyond the self-reported measures of disability in evaluation of actual health status changes and decision making about health interventions.[25]

Cognitive function among the Chinese oldest-old was substantially and significantly worse in the later oldest-old cohorts compared with the earlier cohorts, consistent with the trends reported in the other studies in mainland China, Hong Kong, and Taiwan.[17,18] However, the Danish 1915 cohort scored significantly better for cognitive function (as assessed by the Mini Mental State Examination) than did the 1905 cohort.[19] We believe the explanation for this disparity lies in cross-cohort

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differences in education. For the two sexes combined, the weighted average education levels of the three Chinese later cohorts born in 1903–08, 1909–18, or 1919–28 were significantly lower than that of the three corresponding cohorts born 10 years earlier, adjusted for age, sex, rural or urban residence, and marital status. The weighted average proportion of frequently going to bed hungry as a child (retrospectively self-reported) among the later cohorts was 30·5% higher than in the earlier cohorts. Such cross-cohort differences in educational attainment and childhood conditions probably resulted from the increase in domestic wars during the periods when the later cohorts were children, compared with the earlier cohorts. This finding implies that the poorer education, childhood conditions, and subsequent adult socioeconomic status experienced by the later cohorts contributed to their lower cognitive function score, as shown in other studies using the CLHLS data.[26] This effect was in addition to the costs of success effects, which resulted in some frail elderly individuals being saved from dying but surviving with poor cognitive function. However, the average education level in the Danish 1915 cohort was significantly better than in the 1905 cohort (p=0·006). Because higher education level is strongly associated with improved cognitive function in old age,[27] the positive effects of increased education level in the Danish later cohort might surpass the negative effects of the costs of success on cognitive function.

We observed that the magnitude of the difference in changes of physical and cognitive functions between the later and earlier oldest-old cohorts was substantially larger in our Chinese study than in the Danish study. For example, the difference in annual rates of changes in disability of activities of daily living between the later and earlier cohorts among Chinese nonagenarians was 2·3%, by contrast with the 1·1% reported for the Danish nonagenarian cohorts. Such differences in magnitude of changes are understandable, because China is still undergoing rapid health transition and socioeconomic development, whereas Denmark passed this stage a few decades ago.

Understandably, self-reported life satisfaction and good health substantially fell among the Chinese oldest-old cohorts interviewed in 2008 compared with the oldest-old cohorts interviewed in 1998 (appendix), because the later cohorts had significantly worse scores for physical performance and cognitive function and their expectancy for good life and health was higher with increased living standards. By contrast with the Chinese results, the opposite trend was observed in the Danish cohorts where the fraction of individuals with excellent self-reported health increased substantially (unpublished data).

The period cross-sectional comparisons among difference age groups interviewed in the same year (2008) showed that the scores measuring capacities of self-reported activities of daily living, objective physical performance, and cognitive function decreased largely

	Age 80–89 years in 1998 or 2008						Age 90–99 years in 1998 or 2008						Age 100–105 years in 1998 or 2008					
	Both sexes combined	p value	Men	p value	Women	p value	Both sexes combined	p value	Men	p value	Women	p value	Both sexes combined	p value	Men	p value	Women	p value
Evidences could support benefits of success																		
Mortality during follow-up	−0·7%	0·0059	−1·3%	0·0671	−0·3%	0·2640	−0·3%	0·0647	−0·6%	0·1178	−0·2%	0·1859	−0·7%	0·0032	−1·0%	0·0557	−0·4%	0·0163
Mean ADL disability score	−2·4%	0·0023	−2·8%	0·0290	−2·5%	0·0257	−2·3%	<0·0001	−2·2%	0·0082	−2·3%	<0·0001	−2·3%	<0·0001	−0·8%	0·0604	−2·8%	<0·0001
Evidences could support costs of success																		
Physical performance capacity score																		
Stand up from chair	−0·7%	<0·0001	−0·6%	<0·0001	−0·9%	<0·0001	−1·0%	<0·0001	−0·8%	<0·0001	−0·9%	<0·0001	−0·8%	0·0012	−1·0%	0·0064	−0·5%	0·0184
Pick up book from floor	−0·6%	<0·0001	−0·4%	<0·0001	−0·6%	<0·0001	−1·3%	<0·0001	−1·1%	<0·0001	−1·4%	<0·0001	−1·3%	<0·0001	−1·4%	0·0061	−1·0%	0·0004
Turn around 360°	−1·1%	<0·0001	−0·9%	<0·0001	−1·4%	<0·0001	−2·7%	<0·0001	−2·4%	<0·0001	−2·8%	<0·0001	−3·3%	<0·0001	−3·8%	<0·0001	−2·8%	<0·0001
Cognition capacity (MMSE score)	−0·8%	<0·0001	−0·7%	<0·0001	−0·9%	<0·0001	−1·6%	<0·0001	−1·4%	<0·0001	−1·7%	<0·0001	−2·2%	<0·0001	−1·7%	<0·0001	−2·2%	<0·0001

Annual rates of changes presented in this table are estimated based on comparing the mean annual death rates, mean ADL disability scores, mean physical performance scores and mean MMSE scores between the earlier and later cohorts at the same age in the two survey timepoints of 10 years apart; p-values are taken from tables 1–3; they are the results of multivariate model tests of the difference between the earlier and later cohorts, adjusted for age, education, rural or urban residence, and marital status; when the two sexes were combined, the gender was also adjusted for. ADL=activities of daily living. MMSE=Mini-Mental State Examination.

***Table 4:* Annual rates of changes in mortality, ADL disability, and physical and cognitive function between same-age cohorts across the two survey timepoints**

from ages 80–89 years to 100 years or older, but the proportion of the oldest-old individuals reporting satisfaction and good health slightly increased or remained almost unchanged across these ages (appendix). This finding is consistent with research about optimism and survival in the Danish 1905 cohort,[28] and three Danish population-based surveys (including 11 307 participants aged ≥45 years, of whom 2411 were 90 years or older), which demonstrated that decline in activities of daily living and cognitive function did not necessarily affect happiness at older ages.[29] Our findings in the Chinese setting and the Danish findings might suggest that being more positive in one's outlook on life (ie, optimism and happiness) could increase the chance of longevity.

Our study has important limitations and further research is needed. For example, additional in-depth studies are warranted to develop a deeper understanding of the mechanisms and causalities of how and why mortality and activities ofdaily living disability risk significantly declined due to benefits of success, whereas the objective tests of physical performance and cognitive function were significantly reduced due to the effects of costs of success. We did not investigate trends in the prevalence of clinically diagnosed chronic diseases (an important aspect of morbidity) between the earlier and later cohorts, and we did not make comparisons for the representative samples of young-old cohorts born 10 years apart because of insufficient data (appendix). Further studies need to extend our analysis to cover all elderly age groups and include chronic diseases to fully understand the process of healthy aging in a lifecourse perspective, with a sufficiently large sample size of both oldest-old and young-old cohorts. In-depth research into the trends between various health outcome indicators might provide solid evidence for health intervention programmes aimed at strengthening the positive effects of the benefits of success and reducing the negative effects of the costs of success. This research would fundamentally contribute to the sustainable development of human societies in the face of worldwide rapid population aging with increased longevity.

Populations in China and many other countries in the world are aging rapidly. The oldest-old will increase much faster than any other age groups. The findings of the present study and other research[10,13,14,17–19,30] provide a clear warning message to societies with aging populations, namely that although individuals enjoy increasing longevity and improvement in some health indicators (benefits of success), other major health indicators can deteriorate (costs of success). This effect poses enormous challenges for health systems, social care, and families, not only in China but also globally, especially in other low-income and middle-income countries. The situation calls for policy actions. Thus, we believe that, to fully harvest the benefits and reduce the costs of the success from increasing lifespans, it is crucially important to develop many more state-subsidised public and private programmes and enterprises to provide services to meet the various needs of the growing elderly populations of both the oldest-old and young-old in China and worldwide. These measures should include long-term and acute daily care and mobility aids for people with disabilities, working opportunities for those elderly individuals who are still active, service and individualised intervention programmes for social and leisure activities, continued learning, opportunities for tourism, psychological counselling, and remarriage bridge-building.

Contributors
YZ designed the study and drafted the paper. QF performed the statistical data analysis and worked with YZ to draft the paper. All authors discussed and contributed to the theoretical framework, interpretation of the results, and revised and gave final approval of this manuscript.

Declaration of interests
We declare no competing interests.

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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

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Survival, disability in activities of daily living, physical and cognitive functioning among the oldest-old in China: a cohort study

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Online Appendix

A1. A note about the two contrasting scenarios of health trends in aging populations

As discussed in the Introduction section, there is contention around two contrasting scenarios of health trends in aging populations. One view states that advances in medical technology, improvements in lifestyle and socioeconomic development will postpone the onset of disability and chronic diseases among the elderly, so that morbidity will be "compressed" in old age.[1-3] Some scholars named this trend as "success of success" that is, people are living longer (success) and in better health at older ages than previously (success).[2,3] In contrast, it is hypothesised that prolonged lifespan results in more frail elderly surviving with health problems, thus worsening the overall health of the elderly population. This is often referred to as expansion of morbidity, which was named by some scholars as "failure of success".[4,5] It is argued that these two trends may coexist and interplay in reality,[6] and a moderate concept of a "dynamic equilibrium" was introduced to understand the relation of morbidity and the life expectancy increases.[7] Based on our present and prior studies, we believe that, compared to the wording of "failure of success" which sounds somewhat too pessimistic and may mislead people who are not experts in aging studies, the term "costs of success" may more accurately present the reality, because many oldest-old do enjoy their lives although they have to face the challenges of disability. Thus, we propose to use "costs of success" to summarize the phenomenon of expansion of morbidity (including disability and chronic diseases) with increasing longevity, and accordingly, to use "benefits of success" to summarize the compression of morbidity. Our present analyses support the coexistence of these two trends.

A2. The CLHLS sampling design

The Chinese Longitudinal Healthy Longevity Study (CLHLS) is a nationwide survey conducted in a randomly selected half of the counties and cities in 22 of the 31 provinces, covering about 85 percent of the total population of China. The CLHLS adopted a targeted random-sample design to ensure representativeness, even distribution across age and gender and sufficient sub-sample size of the oldest-old aged 80+, plus compatible young-old aged 65-79. The CLHLS surveys tried to interview all centenarians who voluntarily agreed to participate in the study in the sampled counties and cities. For each centenarian interviewee, the CLHLS randomly selected and interviewed one nearby octogenarian and one nearby nonagenarian of predefined age and sex. Since the 2002 wave, the CLHLS was expanded from only recruiting oldest-old in 1998 and 2000 waves to also interviewing approximately three randomly selected nearby elders aged 65-79 of predefined age and sex in conjunction with every two centenarians. "Nearby" is loosely defined – it could be in the same village or in the same street, if available, or in the same sampled county or city or another sampled neighboring county or city.[8] The targeted random-sample design with approximately equal male and female nonagenarians, octogenarians and young-old living "nearby" the centenarians aimed to investigate determinants of healthy longevity of different and comparable age and gender groups, who live in the same social and natural environment.

One of the limitations of many other nationwide healthy aging studies is proportional sampling, which resulted in very small sample size at oldest-old ages 80+, especially for male oldest-old.

In contrast, the CLHLS purposively over-sampled the oldest-old, resulting in the world's largest sample size of male and female centenarians, nonagenarians and octogenarians. Consequently, appropriate weights based on the census and the CLHLS data were used to compute the averages of the age groups.[8,9] The method for computing the age-sex-rural/urban-specific weights and the associated discussions are presented in the reference [2] and are also available on the CLHLS Website (https://sites.duke.edu/centerforaging/programs/chinese-longitudinal-healthy-longevity-survey-clhls/).

A3. Follow-up interviews and new recruits to replace deceased and lost-to-follow-up participants

All of the CLHLS follow-up surveys include re-interviews of survival participants, and information about the date/cause of death, degree and length of disability of the elderly who were interviewed in the previous wave, but died before the subsequent survey date was collected by interviewing a close family member of the deceased participants. In the first four nationwide follow-up surveys conducted in 2000, 2002, 2005 and 2008, CLHLS also included new recruits to replace all deceased and lost-to-follow-up elders of the same sex and age, but no such new recruits as replacement were included in the CLHLS 2011 and 2014 nationwide follow-up surveys (due to budget constraints), except in the eight selected longevity areas where the density of centenarians was exceptionally high.[8]

Consequently, the CLHLS participants of the oldest-old interviewed in 1998 and 2008 were nationally representative samples, and adequate for comparative analysis of cohorts born ten years apart. However, we could not include comparison for the young-old cohorts born 10 years apart in the present study, because the CLHLS participants aged 65-79 interviewed in 2011 or 2014 were only survivors from those interviewed in the 2008 wave, but they were not a nationally representative sample, and not compatible with the young-old participants recruited in 2002 for the first time.

A4. Data quality

Scholars have conducted extensive evaluations of the data quality of all CLHLS waves, including assessments of mortality rate, proxy use, non-response rate, sample attrition, reliability and validity of major health measures, and the rates of logically inconsistent answers, with generally satisfactory results compared to other major aging studies. For example, factor analyses on cognitive functioning, physical performance, and functional limitations demonstrate that the interviewees' answers to questions concerning different aspects of the same category are generally consistent. The rates of logically inconsistent answers and incomplete data are low (1-3%). We did not find substantial underreporting of death rates in the CLHLS surveys. The morbidity data in CLHLS are slightly better than that in the National Health Service Survey.[10] Careful assessments have assured that the data quality of the CLHLS is reasonably good [8-12]

Another approach to assess the survey data quality is to check whether the age-sex-specific death rates follow a general age-sex trajectory pattern commonly found in other populations with good data quality. The analysis[13] revealed that the single-age-sex-specific mortality rates at oldest-old ages, including centenarians, fit well with the Kannisto model, a function that is evidenced to best fit human mortality trajectories at oldest-old ages in multiple countries with high quality data.[14] These results support the conclusion that the data quality of the oldest-old in the CLHLS is reasonably good.[13,15] It was also discovered that some health indicators revealed in CLHLS were quite similar to the other Chinese surveys. For example, Dr. Danan Gu (a senior research fellow of U.N. Population Division) compared the age-sex weighted average overall prevalence rates of self-reported diabetes, heart disease, hypertension and stroke between the CLHLS and the National Health Service Survey (NNHS) conducted by the National Health and Family Planning Commission of China as well as between the CLHLS sub-sample in Shanghai and another independent health survey on older adults jointly conducted by Shanghai University and the Research Center on Aging of Shanghai Municipality. Dr. Gu found similar overall prevalence rates across the CLHLS and the NHSS as well as between the CLHLS-Shanghai and the Shanghai health survey. Note that in all population-based health surveys, the self-reported data (rather than clinically identified) about chronic diseases may be subject to significant under-estimation, especially in rural areas where medical services are poor. Thus, we did not use such data in the present study.

A5. Study population of the cohorts in present comparative analysis

We compare the following three pairs of cohorts of octogenarians, nonagenarians and centenarians, and the two cohorts in each pair of the comparison born ten years apart, with the same age at the time of the assessment in the CLHLS 1998 and 2008 surveys:

(1) Octogenarians: comparison between the cohort born in 1909-1918 (assessed at ages 80-89 with mean age 83.1 in 1998 survey, n=3,235) and the cohort born in 1919-1928 (assessed at ages 80-89 with mean age 83.0 in 2008 survey, n=4,053).
(2) Nonagenarians: comparison between the cohort born in 1899-1908 (assessed at ages 90-99 with mean age 92.1 in the 1998 survey, n=2,896) and the cohort born in 1909-1918 (assessed at ages 90-99 with mean age 92.2 in the 2008 survey, n=4,338).
(3) Centenarians: comparison between the cohort born in 1893-1898 (assessed at ages 100-105 with mean age 101.1 in 1998 survey, n=2,197) and the cohort born in 1903-1908 (assessed at ages 100-105 with mean age 101.7 in 2008 survey, n=2,809).

Table A1 presents the comparisons of the basic demographic characteristics of the cohorts of the oldest-old born ten years apart with the same ages when they were assessed in 1998 or 2008. As can be seen in Table A1, most Chinese oldest-old women were not married and not educated. However, the Chinese oldest-old men were more likely to be married and had better education than their female counterparts.

Table A1. Comparisons of the basic demographic characteristics of cohorts of the oldest-old born ten years apart with the same ages when they were assessed in 1998 or 2008

	Years of birth		Years of birth		Years of birth	
	1909-1918 (n=3235)	1919-1928 (n=4053)	1899-1908 (n=2896)	1909-1918 (n=4338)	1893-1898 (n=2197)	1903-1908 (n=2809)
Ages and year of interview	80-89 in 1998	80-89 in 2008	90-99 in 1998	90-99 in 2008	100-105 in 1998	100-105 in 2008
Mean age (standard division)	83.07 (2.59)	82.98 (2.57)	92.11 (2.13)	92.24 (2.19)	101.15 (1.34)	101.72 (1.55)
Women, n (%)	1995 (61.7%)	2362 (58.3%)	2102 (72.6%)	3144 (72.5%)	1652 (75.2%)	2254 (80.2%)
Rural residence (urban=0):						
Both sex, n (%)	2135 (66.0%)	2186 (53.9%)	1770 (61.1%)	2314 (53.3%)	1342 (61.1%)	1466 (52.2%)
Women, n (%)	1058 (66.4%)	1108 (54.8%)	1007 (60.9%)	1377 (54.5%)	1019 (57.9%)	1237 (56.0%)
Men, n (%)	1072 (65.3%)	1072 (52.8%)	767 (61.7%)	911 (50.3%)	310 (70.6%)	220 (36.7%)
Married:						
Both sex, n (%)	902 (27.9%)	1424 (35.1%)	280 (9.7%)	497 (11.5%)	74 (3.4%)	90 (3.2%)
Women, n (%)	225 (14.1%)	451 (22.3%)	47 (2.8%)	139 (5.5%)	5 (0.3%)	25 (1.2%)
Men, n (%)	822 (50.3%)	1077 (53.1%)	345 (27.7%)	490 (27.1%)	55 (12.6%)	70 (11.6%)
Education for both sexes:						
Not educated, n (%)	2006 (62.2%)	2525 (62.3%)	2129 (73.8%)	3233 (74.8%)	1763 (81.1%)	2389 (85.4%)
Primary school, n (%)	900 (27.9%)	1160 (28.6%)	593 (20.6%)	856 (19.8%)	335 (15.4%)	319 (11.4%)
Above primary school, n (%)	320 (9.9%)	362 (8.9%)	164 (5.7%)	231 (5.4%)	76 (3.5%)	90 (3.2%)
Education of women						
Not educated, n (%)	1286 (81.0%)	1269 (80.7%)	1439 (87.4%)	2180 (86.6%)	1594 (91.8%)	2045 (92.8%)
Primary school, n (%)	227 (14.3%)	315 (15.6%)	174 (10.6%)	283 (11.2%)	118 (6.8%)	127 (5.8%)
Above primary school, n (%)	75 (4.8%)	76 (3.8%)	34 (2.0%)	55 (2.2%)	25 (1.4%)	32 (1.4%)
Education of men						
Not educated, n (%)	525 (32.0%)	748 (36.9%)	469 (37.8%)	792 (43.9%)	214 (49.1%)	328 (55.2%)
Primary school, n (%)	815 (49.8%)	951 (47.0%)	582 (46.9%)	764 (42.4%)	180 (41.2%)	204 (34.4%)
Above primary school, n (%)	198 (18.2%)	327 (16.1%)	189 (15.3%)	246 (13.7%)	43 (9.7%)	62 (10.5%)

Note: The results are weighted averages using the age-sex-rural/urban-specific sample weights as described in section A1.

A6. The data variables analyzed in this article

Mean annual death rates

As described above, information on date of death were collected for the interviewees who were interviewed in 1998 or 2008, but died in the inter-wave period 1998-2000 or 2008-2011. We estimated the age-sex-specific weighted mean annual death rate for each of the cohorts by dividing the weighted total number of deaths among the cohort members in the follow-up period by the weighted total number of person-years lived by all of the cohort members (including those who survived and died).

Activities of Daily Living (ADL) Disability

The ADL functional status of six daily activities of eating, dressing, transferring, using the toilet, bathing, and continence were used to measure the elders' status of independence in daily living. A score of 0 was given to participants needing assistance with the activity, a score of 1 if no help was needed, resulting in a range of 0 to 6 for the ADL scores. ADL is a good measurement of functional capacity and a proxy of health status widely used in healthy aging studies.[16-18] In this study, we follow the ADL capacity group classification widely adopted in the other studies on oldest-old:[19] if none or one of the six ADL activities is impaired, the oldest-old is classified as "normal"; if two activities are impaired, the oldest-old is classified as "moderately disabled"; "severely disabled" refers to those elders who have three or more activities impaired.

Physical performance in three tests

Self-reported subjective measures of disability in activities of daily living have been criticised for their potential to be affected by both differences in availability of associated facilities and perceptions of the participants. The objective performance-based tests are highly recommended as complementary measures in examining physical functions.[20-22] In the Chinese elderly population, the objective performance-based tests have been recently valued as important complementary measures for routinely-used ADL, which help clarify the intrinsic physiological impairment of the elderly and environmental barriers of their daily activities.[23,24]

Three objective physical performance tests were administrated in the CLHLS surveys. The first task asked the respondent to stand from a chair. This test has three levels of outcomes, i.e. "can without using arms" (coded as 1), "can using arms" (coded as 0.5), and "cannot" (coded as 0). The second task is to pick up a book from the floor, and respondents are "can while standing" (coded as 1), "can while sitting" (coded as 0.5), and "cannot" (coded as 0). The last task is to test whether the respondent is able to turn around 360° without help (yes vs. no, coded as 1 or 0).

Cognitive function measured by Mini-Mental State Examination (MMSE)

The MMSE, a global assessment test of cognitive function,[19,25] was adapted to the Chinese cultural context and was carefully tested in the pilot survey.[26] The testing protocol includes 24 items regarding orientation, registration, attention, calculation, recall and language, with a total score ranging from 0 to 30. Following the practice widely adopted in the other studies,[12] we use the MMSE cutoffs to define cognitive function as: severe impairment (0-17), mild impairment (18-22), normal (23-27) and maximum (28-30). Note that a zero score was given to those items to which the interviewee was not able to answer or perform the test, purely due to his or her mental or physical impairment (rather than not willing to answer or perform the test), and no proxy was allowed in performing the MMSE tests.

The missing values for all the variables analysed in this article were mostly less than 1%. Only among the centenarians, a few variables such as MMSE score and physical performances had a relative higher missing rates of 2%-3%. Due to such low missing rates, we did not impute the missing values. In the statistical analyses, we deleted the cases with missing values, and the results have no significant difference compared to those with imputation.

A7. Comparisons of subjective wellbeing between the earlier and later oldest-old cohorts

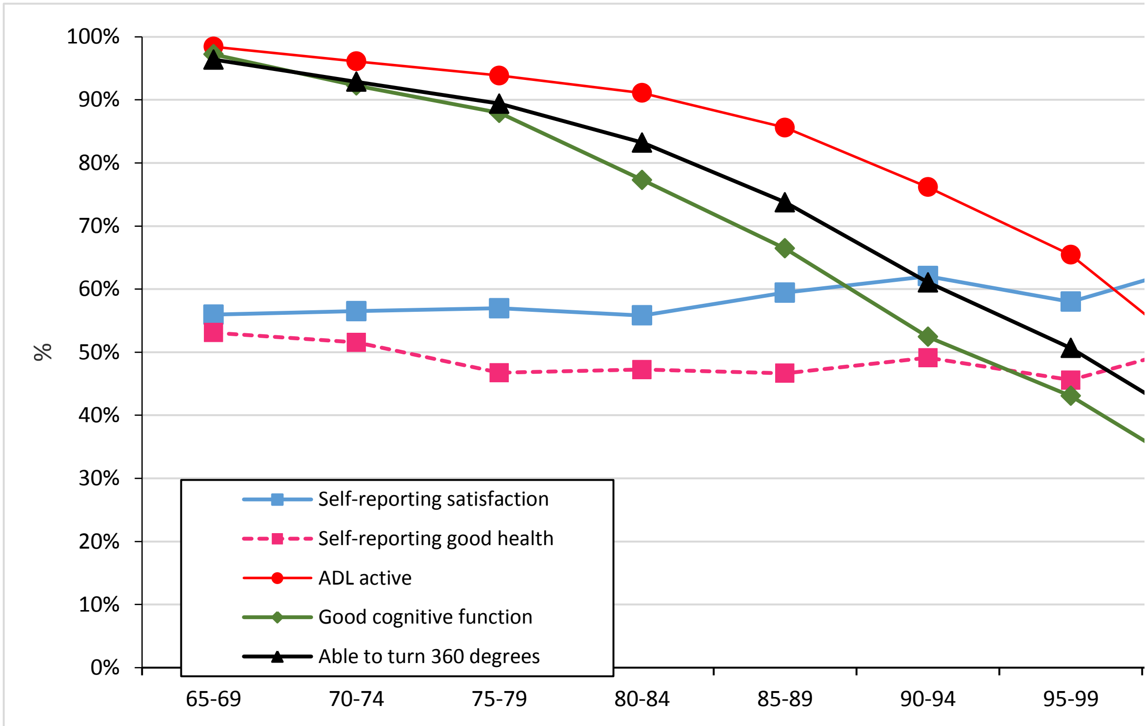
Figure A1. Comparisons of subjective wellbeing between the earlier and later oldest-old cohorts at the same ages interviewed in 1998 and 2008, respectively

Note: Results are based on two genders combined data.

A8. The period cross-sectional comparisons among difference age groups interviewed in the same year

The interesting pattern depicted in Figure A2 has been repeatedly reconfirmed by our multi-wave CLHLS datasets [8, 27] and it reveals that long-lived people, especially centenarians, likely maintain stable life satisfaction independent of their capacities in activities of daily living, physical performance, and cognitive function.

Figure A2. The period cross-sectional comparisons among difference age groups interviewed in the same year 2008



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