




Trends in activities of daily living disability among Chinese older adults from 1998 to 2018: an age-period-cohort analysis

Xiaoqian Hu^{1,2} · Shuyan Gu³ · Xuemei Zhen^{4,5} · Xueshan Sun² · Yuxuan Gu² · Hengjin Dong^{2,6} 

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Abstract

This study aims to investigate the age, period, and cohort effects on trends in activities of daily living (ADL) disability among Chinese older adults; and to explore these three temporal effects on gender and residence disparities in disability. We utilized multiple cross-sectional waves of the Chinese Longitudinal Healthy Longevity Survey data (1998–2018), including 89,511 participants aged above 65 years old. Our measurement of disability is the number of ADL items (dressing, bathing, indoor transferring, toileting, eating, and continence) participants can't perform independently. Hierarchical age-period-cohort cross-classified random effects models were conducted to investigate age, period and cohort trends in ADL disability. Results showed that ADL disability increased with age at an increasing rate. A V-shaped cohort trend and a fluctuated period trend were identified. Females and urban residents were associated with more ADL limitations. When age increased, the gender and residence gaps in disability further increased. The cohort-based gender and residence inequalities in ADL limitations converged with successive cohorts. The period-based residence gap in ADL limitations diverged throughout the 20-year period, while the corresponding period-based change in gender disparity was not significant. These findings suggested that age, period, and cohort had different and independent effects on ADL disability among Chinese older adults. The age effect on trends in ADL is stronger compared to period and cohort effects. The gender and residence disparities in disability increased with age and decreased with successive cohorts. These patterns might help inform healthcare planning and the priorities for medical resource allocation accordingly.

Keywords Age-period-cohort · Activities of daily living · Disability · China · Health disparity

Introduction

In China, life expectancy at birth rapidly increased from 43.83 years in 1950 to 76.62 years in 2015 (United Nations, Department of Economic and Social Affairs, Population Division 2019). Meanwhile, the number of people aged above 65 years old increased from 49.91 million in 1982 to 190.59 million in 2020 (National Bureau of Statistics of the People's Republic of China 2021). Older people usually face higher risk of being disabled and use more medical care (Colombo et al. 2011). The increase in their number and life expectancy may affect the future sustainability of medical care systems and social support programs (Morciano et al. 2015). Hence, concern has emerged about whether this increased longevity among Chinese population will be accompanied by more disability, which may increase the demand for and costs of daily assistance, medical services and long-term care (Liang et al. 2015; Yu et al. 2016).

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✉ Hengjin Dong
donghj@zju.edu.cn

- ¹ School of Politics and Public Administration, Qingdao University, Qingdao, Shandong, China
- ² Center for Health Policy Studies, School of Public Health, Zhejiang University School of Medicine, Zijingang Campus, 866 Yuhangtang Rd, Hangzhou 310058, Zhejiang, China
- ³ Center for Health Policy and Management Studies, School of Government, Nanjing University, Nanjing, Jiangsu, China
- ⁴ Center for Health Management and Policy, School of Public Health, Shandong University, Jinan, Shandong, China
- ⁵ NHC Key Lab of Health Economics and Policy Research, Shandong University, Jinan, Shandong, China
- ⁶ The Fourth Affiliated Hospital, Zhejiang University School of Medicine, Yiwu, Zhejiang, China

A better understanding of disability trends across the life course and over time is crucial to both aging population and whole society, due to disability leads to deterioration in quality of life for individuals and heavy burden for their families and long-term care system (Liang et al. 2015). Numerous studies have shown that the prevalence of age-specific disability decreased in recent years (Liang et al. 2015; Freedman et al. 2002; Feng et al. 2013); while other studies reported an increasing disability trend (Yu et al. 2016; Seeman et al. 2010) or a flat trend (Freedman et al. 2013; Sarkeala et al. 2011). However previous studies rarely adjusted for three unique effects related to disability trends, which are age, period and cohort (APC) effects. The age effect reflects biological and social processes of aging specific to individuals (Reither et al. 2009). The period effect refers to external factors that equally affect all age groups at a particular calendar time. The cohort effect reflects the different formative life experiences for successive generations (Canizares and Badley 2018; Zhang et al. 2020). As each temporal dimension distinctively contributes to the study of health, these temporal sources of variations in disability need to be distinguished. Failure to isolate APC effects would lead to bias and confounding results of disability trends (Zhang et al. 2020).

In order to examine the disability trends accurately, researchers began to estimate APC effects simultaneously, but could be improved further. An American study found that when adjusted for APC effects, a stable period trend and an increasing cohort trend in activities of daily living (ADL) disability were shown. However, unadjusted cohort trends in ADL disability showed continual declines (Lin et al. 2012). A European study covering 15 countries identified a small overall changes in disability over time periods and a U-shaped cohort trend (Beller and Epping 2021). A Hong Kong study found an increasing period trend in ADL disability from 2003 to 2012 and no significant cohort trend. The relative short cohort range (from 1904 to 1947) in this study may influence the exploration of cohort effects (Yu et al. 2016). Another study in China reported that ADL disability slowly increased from 1998 to 2014 and decreased with successive cohorts (Zhang et al. 2020). While this study used intrinsic estimator method for the APC analyses, this method may be a poor approximation to the process of social change and would produce larger bias in small samples when the underlying effects were zero than when they were not zero (Yang and Land 2009). Meanwhile it only focused on those people aged 80 years and above, which may not reflect the age effects entirely. Given these limitations in previous studies, researches using advanced methods to explore APC effects on disability trends in a longer time span are needed. While due to the identification problem induced by the exact linear dependency between APC (period = age + cohort), it is not possible to directly estimate the linear effect of any

one of the APC variables holding the other two constant (Fosse and Winship 2019). Nowadays, numerous strategies to separate APC effects were developed, such as constrained generalized linear model (CGLM) (Fienberg and Mason 1979), APC model with intrinsic estimator algorithm (Yang et al. 2004), APC characteristic model (APCCM) (O'Brien 2015), hierarchical APC growth curve model (HAPC-GCM) (Lynch 2003) and hierarchical APC cross-classified random effects model (HAPC-CCREM) (Yang and Land 2006). The HAPC-CCREM was developed by Yang et al. in 2006, in which period and cohort effects are treated as level 2 variables to solve the identification problem (Yang and Land 2009). The HAPC-CCREM had been a useful tool to identify age, period, and cohort trends in health (Jiang and Wang 2018; Lin et al. 2014) and happiness (Yang 2008). However, some researchers criticized this model. For example, they thought that the estimation of this model would vary with the width of unequal intervals, since the HAPC-CCREM is a type of constrained estimator (Bell and Jones 2014, 2018). While Reither et al. (2015) have already addressed this critique and provided additional support for the use of HAPC-CCREM when analyzing data from repeated cross-sectional surveys. Thus, this study intends to investigate the disability trends among Chinese older adults using the HAPC-CCREM.

Substantial studies had demonstrated that disability disparities were associated with gender (Zeng et al. 2007), race (Lin et al. 2014), residence (urban/rural) (Liang et al. 2015), and socioeconomic status (SES) (Zimmer et al. 2012). However, evidence on cohort-based trends in disability disparities by these factors was limited and with mixed results (Freedman et al. 2002). An American study showed that the black–white disparity in disability decreased with successive cohorts except for ADL disparity among women (Lin et al. 2014). While a UK study reported that SES disparities in disability enlarged in later cohorts (Morciano et al. 2015). A Chinese study reported that cohort effects on gender and residence disparities in disability were not significant (Li 2015). Another Chinese study in Hong Kong reported that cohort-based trends of ADL disability were flat for both genders (Yu et al. 2016). However, most of these studies didn't simultaneously adjusted for APC which may result in biased estimations (Yang and Land 2009); and most of them applied limited waves of longitudinal data. Indeed, a better understanding of the cohort effects on disability disparities by demographic factors and SES is necessary. In China, gender and residence (refer to urban and rural) disparities are two major sources of persistent social inequality (Li 2015). The unique economic, political, social and demographic transitions undergone in China may have distinct cohort effects on disability disparities, which may be different from that in western countries. Therefore, how gender and residence differentials in disability changed over

age, period, and cohort among Chinese older people needs to be studied further.

Delineating disability trends is important in understanding individual's health status as well as estimating the demand of medical and long-term care services. Using data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), one of the best sources of data on Chinese older people with multiple birth cohorts during the 20-year period from 1998 to 2018, this study aims to use the HAPC-CCREM to investigate age, period, and cohort effects on trends of ADL disability; and to explore these three temporal effects on gender and residence disparities in disability.

Methods

Data sources

This study used data of the 1998, 2000, 2002, 2005, 2008, 2011, 2014, and 2018 waves of CLHLS. Zeng had introduced the survey design in detail previously (Zeng and James 2002). The CLHLS is a nationwide survey conducted in a randomly selected half of the counties and cities in 22 Chinese provinces, covering approximately 85% of the total population in China (Zeng and James 2002). The CLHLS attempted to interview all the centenarians from the sampled area who voluntarily agreed to participate in the study. 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 (65–79 years old) living near the centenarians (Zeng et al. 2017). The response rate was 88% if those who were too sick to interview or who had migrated before the interview were considered as non-participants. If those people were excluded, the response rate was 98% (Zeng et al. 2001). According to previous assessment, the quality of the CLHLS data was high in terms of data completeness, reliability and validity (Gu 2008). Every participant provided written informed consent before the survey. The CLHLS has been approved by Research Ethics Committees of Duke University and Peking University. More details about sampling design of the CLHLS are shown in Online Resource.

Study samples

Since the CLHLS conducted over 20 years from 1998 to 2018 including older people across successive cohorts, it was suitable for the exploration of age, period, cohort effects on disability trends. There were 92,860 samples aged above 65 years old in all eight waves. Because the self-reported age after 105 years old was not reliable (Zeng et al. 2002) and most respondents at advanced ages suffered extremely high

and varying levels of disability, which may lead to unstable estimates in analysis (Zimmer et al. 2012), we excluded 2202 participants aged above 105 years old. Then, 1147 participants were excluded further as they missed information on ADL. Thus, the final sample size in analyses was 89,511 (Details of the sample selection are given in Fig S1 in Online Resource).

Variables

ADL disability

Our measurement of disability is the number of ADL limitations. The CLHLS evaluated ADL using six items from the Katz's ADL Index (Katz et al. 1963) including dressing, bathing, indoor transferring, toileting, eating, and continence for every participants in every survey. The number of ADL limitations in this study was calculated as the number of items that participants could not able to do without assistance. It ranged from zero to six, with lower value indicating better physical ability. Participants with one limitation or more were defined as ADL disabled.

Age, period, and cohort

Participants' age divided by ten was grand mean centered for ease of interpretation of the intercept values (Yang and Land 2009). Period indicated the year in which the survey conducted, which included 1998, 2000, 2002, 2005, 2008, 2011, 2014, and 2018. Cohort was the year participants were born in. Participants who were born before 1900 or after 1940 were grouped separately to ensure a sufficient number of participants (Lin et al. 2012; Yu et al. 2016). We subsequently grouped other birth cohorts into five-year bands.

Covariates

Gender (male = 0; female = 1) and current residence (urban = 0; rural = 1) are key stratification factors. We also adjusted for participants' demographic characteristics and SES, which were demonstrated their associations with ADL disability in previous studies (Zimmer et al. 2012; Zeng et al. 2007). Demographic characteristics included birthplace, marital status, and co-residence. Birthplace was dichotomized as urban and rural. Marital status was defined as married, separated (including divorced and separated), widowed and never married. Co-residence was defined as alone and living with others (including household members and living in a nursing home). SES included education and job. Education was defined as illiterate who hadn't received any education and literate. The CLHLS collected participants' job information through the following question 'What was your main occupation before age 60?' Considering most

people were farmers at that time and positive effects from agricultural occupation on ADL ability according to previous studies (Zeng et al. 2007), we classified job into three categories: farmers, professional & governmental personnel (including professional and technical personnel and governmental, institutional or managerial personnel) and others (including industrial worker; commercial or service worker; military personnel and others).

Statistical methods

First, we summarized the basic characteristics of study samples in all and eight waves using means \pm standard deviation or frequency (percentages). Then, we applied hierarchical age-period-cohort models to simultaneously estimate the age, period, and cohort trends of ADL disability for repeated cross-sectional data.

The HAPC model could address classical APC identification problem in two ways (Yang and Land 2009). First, we grouped individuals born in a five-year range into a single cohort to break the linear dependence among the APC dimensions. Second, the nonlinear transformations approach suggested applying a parametric nonlinear transformation, such as polynomials to at least of one of APC dimensions to break their linear relationships (Yang 2008). According to this strategy and previous findings of curvilinear age effects on health (Yang and Land 2009; Li 2015), this study proposed models of ADL limitations as a quadratic function of age.

We then fit HAPC-CCREM to examine APC effects on ADL disability. In each regression model, ADL disability (the number of ADL limitations) was regressed on age in linear and squared terms, and covariates (birthplace, marital status, co-residence, education and job) as needed. The coefficients of period, cohort, gender and residence were allowed to have random effects, which have been increasingly used in social sciences (Yang 2008). This design made it possible to explore the period-based and cohort-based trends of gender and residence disparities in ADL disability. In total, the model took the following form:

Level-1 Model:

$$\text{ADL}_{ijk} = \beta_{0jk} + \beta_1 A_{ijk} + \beta_2 A_{ijk}^2 + \beta_{3jk} S_{ijk} + \beta_{4jk} R_{ijk} + \sum_{p=5}^P \beta_p X_{pijk} + e_{ijk}, e_{ijk} \sim N(0, \sigma^2)$$

where ADL_{ijk} stands for the number of ADL limitations for respondent i (for $i = 1, 2, \dots, n_{jk}$) within period j (for $j = 1, 2, \dots, 7$) and cohort k (for $k = 1, 2, \dots, 10$); A and A^2 denote age and age-squared, respectively; S denotes gender; R denotes residence; X_p denotes the vector of other individual-level variables, including age by gender, age by residence

to test how do gender and residence inequalities in ADL disability vary with age and control variables (birthplace, marital status, co-residence, education and job) that were known to be strongly associated with ADL disability. β_{0jk} is the intercept indicating the cell mean for the reference group at mean age surveyed in period j and belonging to cohort k ; β_1 and β_2 denote the fixed coefficients for age; β_{3jk} and β_{4jk} denote the random coefficients for gender and residence, respectively; β_p denotes fixed coefficients for covariates; P is the maximum number of covariates included; e_{ijk} is the random individual effect or cell residual, which is assumed normally distributed with mean 0 and a within-cell variance σ^2 . Age divided by 10 is grand mean centered for ease of interpretation of the intercept values.

Level-2 Model:

$$\beta_{0jk} = \gamma_0 + u_{0j} + v_{0k}$$

$$\beta_{3jk} = \gamma_3 + u_{3j} + v_{3k}$$

$$\beta_{4jk} = \gamma_4 + u_{4j} + v_{4k}$$

The level-2 models test whether gender and residence disparities in ADL limitations varied by period or cohort through the specifications of random variance components for the random intercept and coefficients. β_{0jk} denotes random intercept, which specifies that the overall mean varies from period to period and from cohort to cohort. γ_0 is the expected mean at the zero values of all level-1 variables averaged over all periods and cohorts; u_{0j} is the overall period effect regarding residual random coefficients of period j averaged over all cohorts with variance σ_{u0} ; v_{0k} is the overall cohort effect in terms of residual random coefficients of cohort k averaged over all periods with variance σ_{v0} . γ_3 and γ_4 are the level-2 fixed effects coefficients that represent the fixed effects of gender and residence, respectively. In order to test whether gender and residence stratifications of ADL limitations varied by period or cohort, we specify that coefficients have period effects (u_{3j} and u_{4j}), and cohort effects (v_{3k} and v_{4k}), whose corresponding random variance components are σ_{u3} , σ_{u4} and σ_{v3} , σ_{v4} . These random variance components of period and cohort since the intercept and coefficients are assumed to have multivariate normal distributions (Yang 2008).

Therefore, in the level-1 model, we could test whether gender and residence gaps in ADL limitations varied with age by including interaction terms of age with gender or residence. The level-2 model could test whether these differentials varied by period or cohort. Based on the combination of two-level models, we conducted seven models to assess the APC effects on ADL limitations and the change of gender and residence disparities in ADL limitations with APC. Model 1 was a two-level model with a fixed effect for

age and random effects for period and cohort to explore the net APC effects on ADL limitations. Model 2 added the key independent variables, gender and residence to explore their influence on ADL limitations. Model 3 added the interactions between age and gender or residence to explore how gender and residence gaps in ADL limitations varied with age. Model 4 adjusted covariates based on Model 3. Then, Model 5 added random effects of coefficient of gender to explore how gender disparities in ADL limitations varied by period and cohort. Similarly, Model 6 added random effects of coefficient of residence to explore how residence disparities in ADL limitations varied by period and cohort. Model 7 combined Model 4–6 to conduct a full model. Analyses were conducted using SAS PROC MIXED (Yang and Land 2009). Bayesian Information Criterion (BIC) was used to compare models concerning the goodness of fit, the smaller BIC value indicating the better model fit (Raferty 1986).

Results

Basic characteristics of samples

Table 1 showed the basic characteristics of samples in all and every survey. There were 89,511 samples in total with an average age of 87.5. There were more females and rural residents in all and most surveys. Most of respondents were born in a rural area, illiterate, working as farmers, living with others and widowed. In total, the average ADL limitations of samples was 0.77 and ranged from 0.62 to 1.05 among eight surveys.

Age-period-cohort trends and differentials in ADL limitations

Table 2 presented estimates of fixed effects of all individual-level covariates and random-effect variance components. From Model 1 in Table 2 and Fig. 1, we identified that net of random period and cohort effects, the effect of age was curvilinear, indicating that ADL limitations increased at an increasing rate as one moved through the life course. Level-2 results suggested that ADL limitations varied in a smaller magnitude by period and cohort, relative to the age effect. The period effect was nearly flat from 1998 to 2008, followed by an upward trend. The cohort effect was V-shaped, indicating the earlier and later cohort had relative more ADL limitations at average compared to middle cohorts. Model 2 indicated that males and rural residents had significantly fewer ADL limitations relative to females and urban residents, when age, period and cohort effects were considered.

Age variations in gender and residence disparities in ADL limitations

Model 3 indicated that the gender and residence disparities in ADL limitations varied significantly with age. When age increased, the gender gap and residence gap further increased. Model 4 revealed that birthplace, education, marital status, job and living condition had significant influences on ADL limitations. Those respondents who were born in rural area, literate, married, living alone and farmers had fewer ADL limitations.

Comparing Model 3 with Model 4, the age, gender and residence effects remained highly significant but decreased a little in size. All the interaction effects remained significant when confounding variables were considered. The interaction effects of gender with age shrank in size, while the interaction effects of residence with age enlarged. The smaller BIC statistic indicated a better model fit for Model 4 than any of the previous models. While this finding was not surprising in light of previous studies of social correlates of ADL disability. It also suggested two findings: one is that the individual-level effects still hold when level-2 heterogeneity, reflecting the period and cohort effects, were taken into account; another one is that net of age and other individual-level covariate, there are significant variations which can be attributed to period-specific factors.

Time trends of gender and residence disparities in ADL limitations

Model 5 and 6 displayed that gender and residence disparities in ADL limitations varied significantly with cohort net of age, period, and other factors. The corresponding period change in residence disparities was significant, while in gender disparities was not significant. From Fig. 2, we found that the gaps in ADL limitations between genders decreased across cohorts, which was largely because of the decreasing ADL limitations for females and relatively stable trends for males among successive cohorts.

Figure 3a demonstrated that residence gaps also decreased across cohorts. Rural residents experienced an upward trend in ADL limitations and urban residents experienced a relatively stable trend. Figure 3b demonstrates that the urban and rural gap was much more pronounced throughout the 20-year period. From 1998 to 2005, rural residents experienced a downward trend in ADL limitations and urban residents experienced some fluctuations. Then from 2005 to 2018, both urban and rural residents showed similar fluctuations and a larger residence gap in more recent years.

Table 1 Basic characteristics of samples in eight surveys

Variables	All	1998	2000	2002	2005	2008	2011	2014	2018
<i>N</i>	89,511	8654	10,944	15,701	15,289	15,541	6885	6476	10,021
Age	87.50 ± 10.62	92.62 ± 7.45	91.35 ± 7.26	86.48 ± 11.44	86.26 ± 11.41	87.30 ± 11.02	85.32 ± 10.19	85.20 ± 9.63	85.63 ± 11.22
Gender									
Male	38,742 (43.3)	3470 (40.1)	4598 (42.0)	6759 (43.0)	6637 (43.4)	6669 (42.9)	3199 (46.5)	3046 (47.0)	4364 (43.5)
Female	50,769 (56.7)	5184 (59.9)	6346 (58.0)	8942 (57.0)	8652 (56.6)	8872 (57.1)	3686 (53.5)	3430 (53.0)	5657 (56.5)
Residence									
Urban	43,099 (48.1)	3219 (37.2)	6770 (61.9)	7236 (46.1)	6834 (44.7)	6314 (40.6)	3954 (57.4)	3028 (46.8)	5744 (57.3)
Rural	46,412 (51.9)	5435 (62.8)	4174 (38.1)	8465 (53.9)	8455 (55.3)	9227 (59.4)	2931 (42.6)	3448 (53.2)	4277 (42.7)
Birthplace									
Urban	12,938 (14.5)	1251 (14.5)	1855 (17.0)	2473 (15.8)	2398 (15.7)	2087 (13.4)	828 (12.0)	639 (9.9)	1407 (14.1)
Rural	76,466 (85.5)	7403 (85.5)	9086 (83.0)	13,176 (84.2)	12,890 (84.3)	13,450 (86.6)	6053 (88.0)	5828 (90.1)	8580 (85.9)
Missing ^a	107 (0.1)	-	3 (<0.1)	52 (0.3)	1 (<0.1)	4 (<0.1)	4 (<0.1)	9 (<0.1)	34 (0.3)
Marital status									
Married	26,569 (29.7)	1422 (16.4)	2079 (19.0)	4719 (30.1)	4774 (31.2)	4661 (30.0)	2557 (37.2)	2516 (39.2)	3841 (38.8)
Separated ^b	1934 (2.2)	155 (1.9)	242 (2.2)	386 (2.5)	352 (2.3)	309 (2.0)	132 (1.8)	127 (2.0)	231 (2.3)
Widowed	59,874 (67.0)	6979 (80.6)	8466 (77.4)	10,401 (66.2)	10,025 (65.6)	10,431 (67.1)	4108 (60.0)	3702 (57.8)	5762 (58.0)
Never married	950 (1.1)	95 (1.1)	156 (1.4)	195 (1.2)	138 (0.9)	140 (0.9)	71 (1.0)	63 (1.0)	92 (0.9)
Missing ^a	184 (0.2)	3 (<0.1)	1 (<0.1)	-	-	-	17 (0.2)	68 (1.1)	95 (0.9)
Co-residence									
With others	76,839 (85.8)	7766 (89.7)	9634 (88.0)	13,596 (86.6)	13,222 (86.5)	13,150 (84.6)	5796 (84.2)	5247 (81.0)	8428 (84.1)
Alone	12,672 (14.2)	888 (10.3)	1310 (12.0)	2105 (13.4)	2067 (13.5)	2391 (15.4)	1089 (15.8)	1229 (19.0)	1593 (15.9)
Education									
Illiterate	53,946 (60.3)	5847 (67.6)	6974 (63.7)	9643 (61.4)	9265 (60.6)	9732 (62.6)	3831 (55.6)	3584 (55.3)	5070 (50.6)
Literate	35,565 (39.7)	2807 (32.4)	3970 (36.3)	6058 (38.6)	6024 (39.4)	5809 (37.4)	3054 (44.4)	2892 (44.7)	4951 (49.4)
Job									
Farmer	64,765 (72.7)	6508 (75.2)	7837 (71.7)	11,153 (71.4)	10,835 (71.0)	11,587 (74.7)	4987 (72.5)	4918 (77.1)	6940 (70.1)
Professional and governmental personnel	7243 (8.1)	615 (7.1)	831 (7.6)	1368 (8.7)	1308 (8.6)	1119 (7.2)	595 (8.7)	455 (7.1)	952 (9.6)
Others ^c	17,131 (19.2)	1530 (17.7)	2269 (20.7)	3107 (19.9)	3108 (20.4)	2814 (18.1)	1290 (18.8)	1009 (15.8)	2004 (20.3)
Missing ^a	372 (0.4)	1 (<0.1)	7 (<0.1)	73 (0.5)	38 (0.2)	21 (0.1)	13 (0.2)	94 (1.5)	125 (1.2)
ADL limitations	0.77 ± 1.58	1.05 ± 1.75	0.94 ± 1.68	0.78 ± 1.53	0.68 ± 1.51	0.62 ± 1.47	0.75 ± 1.58	0.67 ± 1.53	0.79 ± 1.66

ADL activities of daily living. Data are presented as mean ± standard deviation or *n* (%)

^aMissing data were excluded from other percentage calculation

^bThis category included divorced and separated

^cThis category included industrial worker; commercial or service worker; military personnel and others

Discussion

Using eight waves of the CLHLS data from 1998 to 2018, we applied the HAPC-CCREM to explore trends of ADL disability among Chinese older adults. Our findings indicated that the number of ADL limitations increased with age at an increasing rate. We also found a V-shaped cohort trend and a fluctuated period trend. Females and urban residents were associated with more ADL limitations. When age increased, the gender and residence gaps in disability further increased. The cohort-based gender and residence inequalities in ADL limitations converged with successive cohorts. The period-based residence gap in ADL limitations diverged throughout

the 20-year period, while the corresponding period-based change in gender disparity was not significant.

A V-shaped trend was found among successive cohorts, indicating the earlier and later cohort had more ADL limitations at average compared to middle cohorts, which was consistent with previous studies (Beller and Epping 2021; Lin et al. 2014). Beller and colleagues used data from 15 European countries found that when adjusted for APC effects simultaneously, a general cross-country U-shaped birth cohort effect was shown for overall disability (Beller and Epping 2021). According to previous researches, there were two opposing processes, compression of morbidity and expansion of morbidity, influenced health of older people

Table 2 HAPC-CCREM estimates of ADL limitations

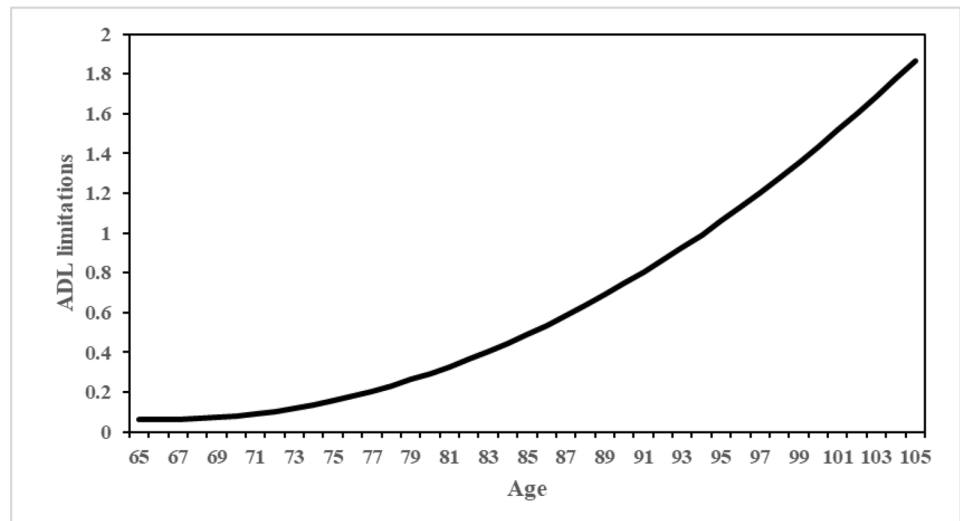
Fixed effects	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Intercept	0.610***	0.020	0.584***	0.032	0.581***	0.032	0.590***	0.038	0.575***	0.032	0.585***	0.029	0.586***	0.037
Age	0.511***	0.015	0.576***	0.010	0.546***	0.012	0.526***	0.012	0.520***	0.014	0.626***	0.008	0.523***	0.011
Age ²	0.119***	0.006	0.177***	0.006	0.164***	0.006	0.154***	0.006	0.170***	0.006	0.175***	0.006	0.155***	0.006
Gender (female=1)			0.156***	0.010	0.171***	0.010	0.163***	0.012	0.155	0.066	0.158***	0.010	0.165***	0.023
Residence (rural=1)			-0.165***	0.010	-0.168***	0.010	-0.111***	0.011	-0.167***	0.010	-0.151	0.070	-0.108**	0.026
Age * Gender					0.140***	0.010	0.135***	0.010					0.137***	0.011
Age * Residence					-0.114***	0.009	***	0.009					-0.124***	0.012
Birthplace (rural=1)							-0.068 ***	0.015					-0.067***	0.015
Education (literate=1)							-0.050 ***	0.012					-0.051**	0.012
Marital status (ref = married)														
Separated							0.136 ***	0.034					0.137***	0.034
Widowed							0.127 ***	0.014					0.127***	0.014
Never married							0.051	0.049					0.051	0.049
Job (ref = farmer)														
Professional and governmental personnel							0.146***	0.020					0.149***	0.020
Others							0.107***	0.014					0.108***	0.014
Living condition (alone = 1)							-0.438***	0.015					-0.438***	0.015
Variance components														
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7							
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Period														
Intercept	0.002*	0.001	0.006*	0.003	0.006*	0.003	0.007*	0.004	0.004*	0.002	0.005*	0.003	0.007*	0.004
Gender									0.007	0.004			0.003	0.002
Residence											0.014*	0.008	0.003	0.002
Cohort														
Intercept	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.004	0.003	0.0004	0.0004	0.001	0.001
Gender									0.034*	0.017			0.0004	0.001
Residence											0.030*	0.015	0.001	0.001
Model fit														
BIC	385,895.4		321,776.7		321,438.0		318,341.2		321,609.0		321,632.1		318,297.8	

HAPC-CCREM hierarchical age-period-cohort-cross-classified random effects model, ADL activities of daily living, SE = standard error, BIC = Bayesian Information Criterion

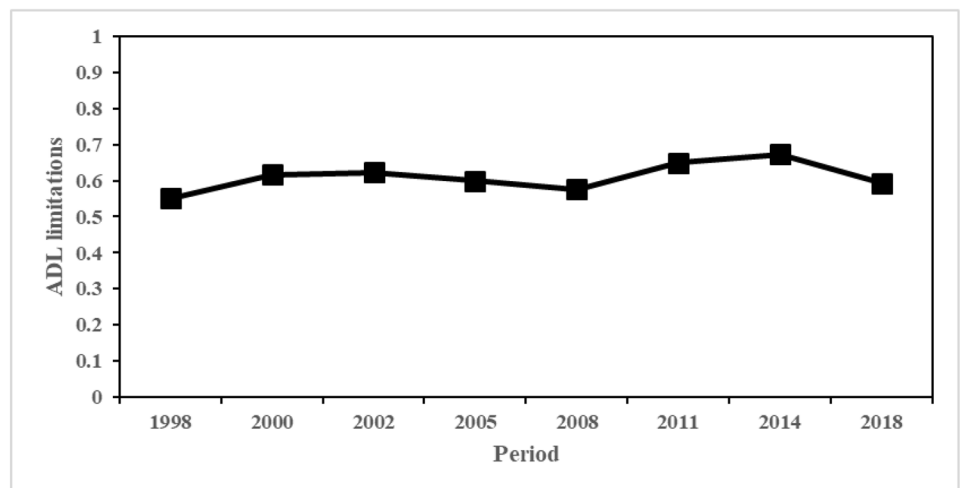
* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Fig. 1 Overall age, period, and cohort effects on ADL limitations

(a) Age



(b) Period



(c) Cohort

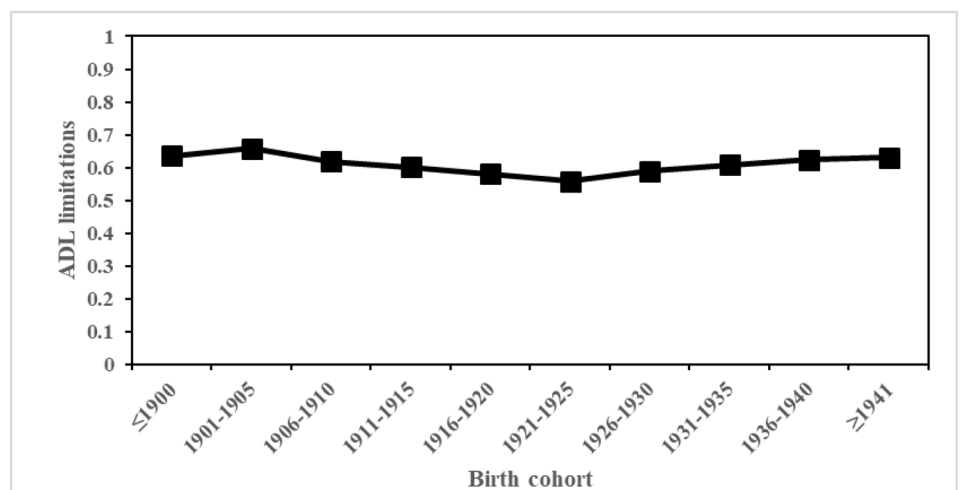


Fig. 2 Predicted cohort variations in gender disparity in ADL limitations

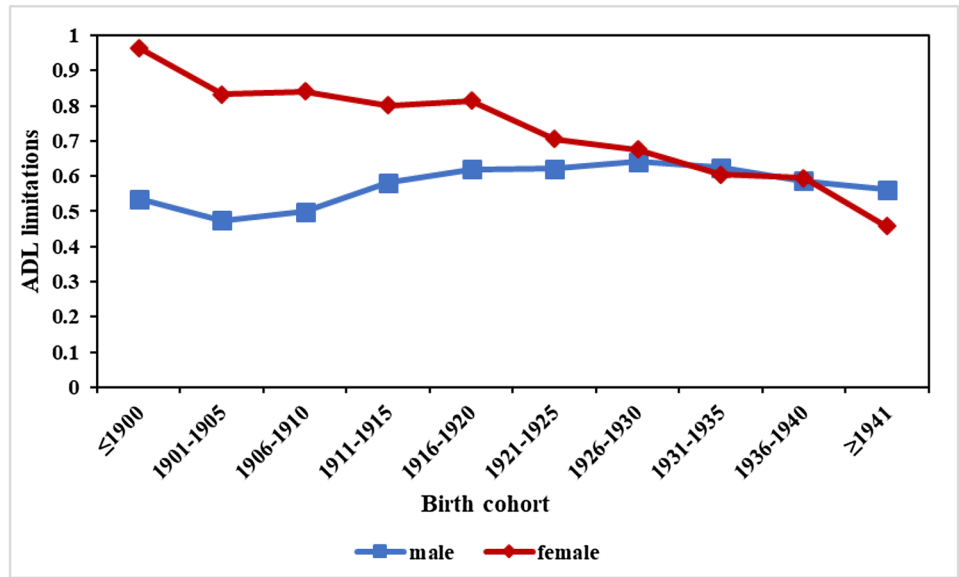
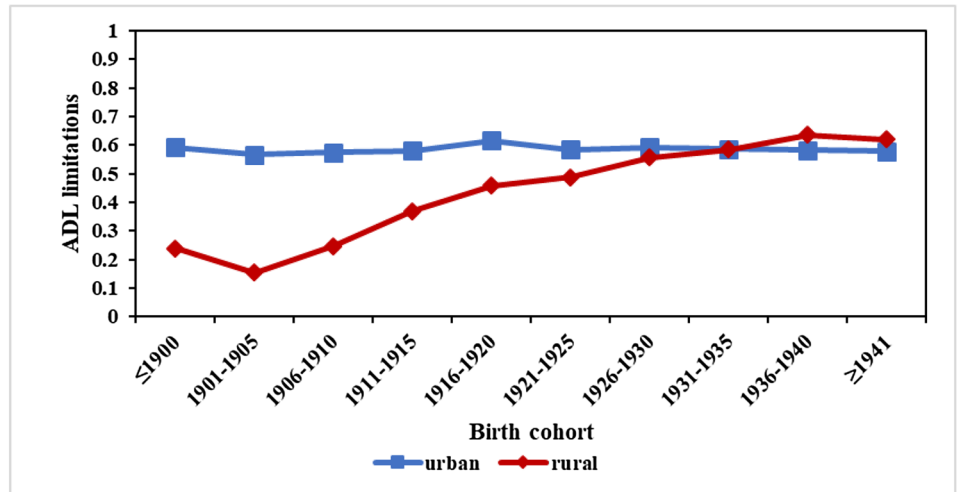
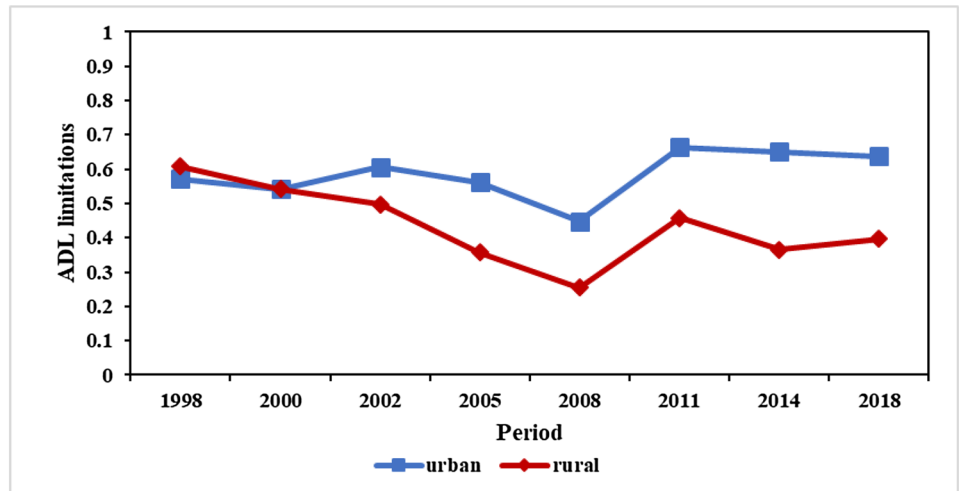


Fig. 3 Predicted cohort and period trends in residence disparity in ADL limitations

(a) Cohort



(b) Period



(Zeng et al. 2017). Compression of morbidity is that the later cohorts might benefit from progress in advanced disease treatment, declining disability effects of some chronic diseases, and improved standards of living. These benefits of success imply that the later cohorts could reach older ages with better health and functional capacity in daily living. While expansion of morbidity is that improvements in medical conditions and living standards in recent years may increase the survival rate of individuals in relatively poor health status, which might increase overall ADL disabilities (Zeng et al. 2017). Participants in earlier cohorts who could survive to advanced age suffering possible hardships in early life stage were likely to be more robust. Those weaker individuals in earlier cohorts almost died before the advanced age (Zeng et al. 2007), only those healthier were still alive. Thus, process of compression of morbidity might be dominate from the earliest cohort to middle cohort, leading to a downward cohort trend among them. While older adults in middle cohort to latest cohort were relatively young, the selective survival effect may be weaker (Yu et al. 2016). Thus, process of expansion of morbidity might be dominate from the middle cohort to latest cohort, leading to an upward cohort trend among them.

The period effects on ADL limitations were minor and fluctuated, which is consistent with the findings from previous studies (Lin et al. 2012; Martin et al. 2011; Beller and Epping 2021). An American study reported ADL disability remained stable across time when adjusted for age, cohort, and other sociodemographic variables (Lin et al. 2012). ADL disability referred to the culmination of the disablement process, which typically represented severer limitations than that of instrumental activities of daily living (IADL) or physical functioning (Zimmer et al. 2012). Thus, the period change on ADL disability may not be obvious and sensitive. Further observation of period-based trend on ADL disability in a longer period is needed.

We identified that males had significantly fewer ADL limitations than did females, which was in line with the previous studies (Zimmer et al. 2012; Crimmins et al. 2011, 2019; Zeng and James 2002). According to previous findings, females have lower grip strength measures, slower gait speed and worse balance compared with males (Ahrenfeldt et al. 2019; Wheaton and Crimmins 2016). Thus, the general weakness of women's physique compared with men might influence the gender gap in ADL. In addition, this gap between genders is more marked with increasing age, thus confirming findings from other studies (Oksuzyan et al. 2010; Scheel-Hincke et al. 2020; Serrano-Alarcón and Perelman 2017). A widening of the gender difference in ADL with increasing age may be consistent with the survival effect, which could leave the healthiest men in the sample (Austad and Fischer 2016). Meanwhile, cumulative disadvantage theory believed that effects of risk factors would

accumulate over the life course, thus increasing heterogeneity in later life (Ferraro and Kelley-Moore 2003). Those individuals experienced disadvantages in early life would face a cascade of additional risks to health and well-being throughout their lives (O'Rand and Hamil-Luker 2005). Due to the preference for sons in old Chinese society (Zhang et al. 2008), a majority of females experienced relatively tough early lives than males, reflecting in their lower possibilities to get adequate food, education and medical service during sickness (Zeng et al. 2007). Thus, very careful attention should be given to females to prevent or postpone the onset of disability and to ensure they obtain adequate care.

In line with other studies (Li 2015; Zeng and James 2002), we found that urban residents were more disabled than rural residents were and this disparity diverged with increasing age. There was a household registration system (*Hukou*), which divided population into agricultural and nonagricultural area with different economic, social and healthcare systems in China (Chen et al. 2010). The living standards and access to health care in rural area were much worse than urban area for a long time (Li 2015). There are some potential explanations for residence disparity. First, most of rural residents did agricultural work, which could help them to maintain their capacity for daily living. Almost urban residents did non-manual work before they were retired. They may not engage in as much physical activity as rural residents did (Zeng and James 2002). Second, there are more facilities available to assist older adults in urban area than in rural area. Therefore, rural residents have to perform daily activities by themselves, which could help them to maintain their physical capacity for a longer time (Zeng and James 2002).

We found that gender and residence disparities in ADL limitations varied significantly with cohorts. When confounding factors were adjusted, these stratifying effects were not statistically significant. Meanwhile, the gender and residence gaps were larger in the earlier cohorts than in the later cohorts. The reduced gender gap may largely due to the decreasing ADL limitations for females among successive cohorts. The improvement in ADL ability for females in later cohorts may partly due to the increasing schooling rate (Liang et al. 2015). Previous studies also demonstrated that the increase in educational achievements might contribute to favorable ADL trends in late life (Lin et al. 2014; Freedman et al. 2002). Due to increasing disabilities among rural residents in later cohorts, the residence gaps converged. One potential explanation may be that in earlier cohorts, there were more rural residents did agricultural jobs, which may help them maintain their capacity for daily living (Zeng and James 2002). The proportion of farmers reduced in later cohorts, thus their advantages in ADL abilities may have diminished somewhat. Another potential explanation was related to the selective survival effect. Due to large gaps

of living conditions between urban and rural area in earlier cohorts, rural residents who endured such hardship in life and survived tend to be healthier than urban residents (Zeng and James 2002; Zimmer et al. 2012). With the rapid development and improvement of rural economic and social conditions, the gaps of overall living conditions between urban and rural area were gradually narrowing in later cohorts, thus the effect of death selection may be reduced as well. More rural residents in relatively poor health status were saved by improved medical conditions, which might increase overall ADL disabilities in rural area (Zeng et al. 2017).

This study had some limitations. First, ADL disability was a self-reported indicator rather than more objective tests of function status. While, for the CLHLS, the results of ADL and other objective health measures show good internal consistency and construct validity (Gu 2008). In future work, other objective indicators of functional status such as grip strength or the chair stand test could be used to obtain a more complete picture of APC trends in health (Beller et al. 2019). Second, due to the data limitation, the earliest and latest birth cohorts did not capture a full age distribution, which may bias the estimates for cohort trends. Thus, nationally surveillance of health changes could be proceeded. Third, in this study we focused on basic effects of APC and individual variables. Effects from macroeconomic and medical variables on ADL disability should be further explored.

Conclusion

In conclusion, we found that ADL disability increased with age at an increasing rate among Chinese older adults. The gender and residence inequalities in disability enlarged with age, while reduced with cohorts. These findings of dynamics of disability could help forecast future disability trends and care services needed and hence, to inform healthcare planning and the priorities for resource allocation (Yu et al. 2016).

Author contributions All authors contributed to the study conception and design. Material preparation and analysis were performed by XH, SG, XZ, XS, and YG. The first draft of the manuscript was written by XH. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The dataset of CLHLS could be obtained upon application on the website (<https://sites.duke.edu/centerforaging/programs/chinese-longitudinal-healthy-longevity-survey-clhls/>).

Code availability Analyses were conducted using SAS PROC MIXED.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The CLHLS has been approved by Research Ethics Committees of Duke University and Peking University.

Consent to participate Every participant provided written informed consent before the survey.

Consent for publication Not applicable.

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