Demography (2012) 49:291–314
DOI 10.1007/s13524-011-0075-7

Modeling Disability Trajectories and Mortality of the Oldest-Old in China

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Published online: 14 January 2012

Abstract This article uses a group-based modeling approach to jointly estimate disability and mortality trajectories over time based on data from the population aged 80 and older in China, and explores relations of demographic, socioeconomic, and early-life characteristics to membership in gender-specific trajectory groups. A three-group model best fits the data for both males and females. For most groups, predicted numbers of limitations in activities of daily living (ADLs) increase with age, but the pace is gradual in some cases and rapid in others. For each gender, the estimated mortality probability trajectories for the three groups follow a hierarchy that is related to the predicted ADL counts at age 80. Only a few characteristics predict trajectory-group membership. Prior nonagricultural occupation is associated with less favorable disability trajectories for both genders. For females, rural residence, a greater number of children ever born, and having a father who did not work in agriculture are associated with more favorable trajectories. For a small group of males who received education, disability is moderate but changes little with age. Findings may reflect heterogeneity of survival among the least advantaged, as well as a possible expansion of morbidity among a small advantaged group.

Keywords Aging · Activities of daily living · China · Disability · Trajectory

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Introduction

In recent decades, as populations have aged worldwide, the volume of research on disability in late life has grown substantially. This work has provided important evidence regarding characteristics of those at risk for disability and time trends at population levels. Given the inherently dynamic nature of disability among older people, another research focus has been on individual transitions into and out of states of disability. Transitions are typically investigated from one period to the next, but as number of periods and number of starting and ending states increase, modeling and summarizing transitions become increasingly complex. Another challenge has been incorporating mortality into analysis of disability dynamics, an important step because those who survive across periods of observation and those who die in the interim may follow distinctly different disability trajectories. China, with its rapidly aging population, has a particular need for such information, and in this article, we estimate gender-specific trajectories among a sample of Chinese aged 80 to 94 at baseline in 1998. Our analysis adopts a group-based modeling approach that is suited to summarizing large numbers of individual trajectories over multiple intervals and allows for the inclusion of the experience of both survivors and decedents.

Background

Population Aging in China

In recent decades, fertility and mortality, including old-age mortality, have declined dramatically in China. Life expectancy at age 60 in China increased from 16 in 1970 to 20 in 2005, while the probability that a woman age 60 will reach age 80 increased from 46% in 1990 to 62% by 2005 (He et al. 2007). This improvement in survival combined with rapid fertility decline has led to the rapid aging of China's population. Within the next 20 years, the proportion of the population aged 80 and older will nearly triple (United Nations 2009). Because the very old are most likely to experience health problems that are associated with difficulty living independently, population aging will likely challenge the health care system and other nascent programs organized by communities, the government, and the private sector to assist those in need of help. Much of the burden may fall to families who themselves have undergone dramatic structural change as a result of demographic trends and rapid economic growth, perhaps leaving them ill equipped to meet the challenges of caring for older members. A better understanding of the dynamics of disability in China could help target limited resources to the development of support services, as well as interventions to delay the onset or prevent the progression of disability and facilitate recovery at the individual level.

Disability Research

Disability, especially as indicated by limitations in carrying out activities of daily living (ADLs), such as bathing, dressing, and eating (Katz et al. 1963), is the most

commonly used population-level summary measure of health in late life. Various frameworks for understanding disability have been proposed (e.g., Pope and Tarlov 1991; WHO 2002). A common element is the conceptualization of disability as a gap between the capacities of individuals and the demands of a task being carried out within a particular environment. A related element of some of the frameworks is the progression from pathology and impairment at the cellular and organ levels (e.g., arthritis and difficulty bending a knee) to limitation in functioning at the individual level (e.g., crouching) and disability in carrying out a task (e.g., bathing) in a particular environmental context (e.g., a walk-in shower versus a bathtub) (Nagi 1976; Pope and Tarlov 1991; Verbrugge and Jette 1994). ADL disability is viewed as the culmination of the disablement process and typically represents more severe limitation than that of physical functioning or even of instrumental activities of daily living (IADLs), which include routine household tasks. Consequently, the prevalence of ADL limitations is relatively low in comparison with IADL or physical functional limitations in older populations.

Besides the relations of the earlier stages in the disablement process to disability, researchers have examined associations between risk factors and disability. General models of health (see, e.g., Dahlgren and Whitehead 1991; Marmot 1999; Smedley and Syme 2000) suggest many possible factors, but because disability reflects domains beyond health, indicators of living environment and adjustments in how activities are carried out also would ideally be considered, although they rarely are in practice (see, e.g., Verbrugge and Jette 1994; Heikkinen 2003). Some risk factors are not modifiable: for example, age, gender, and genetics. Being older and being female are typically associated with greater risk of disability. Also not modifiable in late life are early-life experiences, such as childhood deprivation or illness, which may have long-term health consequences (Hayward and Gorman 2004). In this category, an intriguing possibility is that earlier childbearing—which reflects many factors, including those that are genetic, biological, and social—may influence late-life health. Zeng and Vaupel (2004) found that in China, late childbearing is positively associated with late-life survival among males and particularly females, and a high number of children ever born (CEB) may imply such late fertility and the possible availability of relatively young offspring to provide care if needed. Other demographic characteristics may change in late life. Although decisions to marry typically are made earlier in life, the loss of a spouse at older ages may influence one's ability to function. Residence in urban versus rural settings represents many factors that may affect disability both positively and negatively: for example, exposures to environmental risks, housing and neighborhood characteristics, and access to health care.

The question of the influence of socioeconomic status (SES) on late-life health is a particularly active area of research (Lynch 2008). It could be that the disadvantage of low SES accumulates throughout life and is manifested in late-life disability outcomes. Alternatively, those who are exposed to early-life disadvantage and who survive to old age may be positively selected, and SES gaps in disability may be reduced or even reversed. Education may influence disability through many mechanisms, including long-term standard of living, health behaviors, access to care, health literacy, the built environment, choice of occupation, and use of assistive devices (Freedman and Martin 1999). Occupation also may influence disability in

many ways, such as through physical activity, physical demands of job and risks of injury, exposures to environmental risks, standard of living, and access to health care (Leigh and Fries 1992).

Compared to studies in the West, multivariate modeling of late-life disability prevalence in China has not revealed as robust associations with SES measures such as education and occupation (Li et al. 2009; Zhao 2008; Kaneda et al. 2010). Results for other sociodemographic factors have been mixed. Being male, being married, and living in urban areas are typically protective, but not always. There is also variation in results from studies that model disability onset, recovery, and progression in China (Beydoun and Popkin 2005; Gu and Zeng 2004; Liang et al. 2001), no doubt in part because of differences in the scope of data sets, not all of which are national.

From Transitions to Trajectories

Although there has been progress in the analysis of two-period disability transitions in many settings and particularly for China, research on multiperiod transitions that occur over long time frames and that are measured using several observation points—typically called trajectories—has been limited. One difficulty has been the shortage of longitudinal data at the population level. But such data are becoming increasingly available. An additional challenge has been adequately summarizing what could be hundreds or even thousands of possible trajectories (Wolinsky et al. 2000). That is, as the number of periods of observation and the number of possible starting states (e.g., not, mildly, moderately, or severely disabled) and ending states (e.g., the earlier examples plus death) increase, the possible individual disability pathways multiply. Although there have been attempts to summarize and characterize such multiperiod trajectories, research remains limited on a global level and is nonexistent in China.

Most studies of disability trajectories have adopted one of two strategies: subjective categorization of pathway types (Ferrucci et al. 1996) or growth-curve modeling (Taylor and Lynch 2004). These strategies have advanced our understanding of the ways in which people experience the dynamic nature of disability that accompanies aging. As is the case for all methods, each of these approaches has limitations and assumptions. For subjective categorization, patterns tend to be established *a priori,* and resultant typologies, although often sensible, may over- or under-fit the data. Moreover, there is no easy test for affirming the existence of each subjectively determined group or for assessing the probability of group membership. As a consequence, subjective categorization may be a function of random variation, and there may be little basis for calibrating the underlying precision of classification decisions. Growth-curve models generally assume that the distribution of trajectories in the population varies continuously across individuals in a form that ultimately can be represented by a multivariate normal distribution. One of the main advantages of this strategy is that it allows formal testing of models. A drawback is that growth-curve modeling is not designed to identify qualitatively distinct groups of disability trajectories. In addition, although it is possible to model mortality within a growth-curve framework, to our knowledge, such modeling has not been undertaken. Instead, models tend to be

estimated for survivors and decedents separately, or survival status is added as a control variable (Li 2005; Yang and Lee 2010).

Less commonly used to investigate disability trajectories are grade of membership models (GoM) (Manton et al. 2008; Stallard 2007). These analyses assume a finite number of pure or so-called extreme types of disability progression in the population. The estimated disability trajectory of any individual is the realization of an individual-specific linear combination of types. Erosheva (2002, 2005) shows that GoM can be considered a generalization of a latent class model and that there is a latent class representation of GoM. However, the number of latent classes and extreme profiles may differ.

In this article, we apply an approach called group-based trajectory modeling, which has some commonalities with GoM but is distinctly different. Group-based trajectory modeling is a specialized application of finite mixture modeling (Nagin 2005; Nagin and Land 1993; Nagin and Tremblay 2001; Roeder et al. 1999). As will be described in detail later, the model's statistical outputs are not a finite number of extreme profiles and accompanying weights for each individual reflecting the contribution of each extreme type to his or her individual trajectory, as in GoM; rather, the outputs are (1) a finite number of trajectory groups that characterize the developmental course of the outcome, in this case disability, and (2) the size of each group as measured by the estimated proportion of the population at baseline that is most likely to follow that trajectory. A critical difference from GoM is that in group-based trajectory modeling, each individual belongs to a distinct qualitative trajectory group, whereas in GoM, individual-level trajectories are determined by a linear combination of extreme types.

Some applications of group-based trajectory modeling have concentrated on such health outcomes as body mass index, depression, and cognition (e.g., Andreescu et al. 2008), and recent applications have focused on disability (Connor 2006; Dodge et al. 2006; Gill et al. 2010; Liang et al. 2010; Taylor 2005). None of these have jointly modeled the outcome of interest and the dropping out of observations, which in the case of late-life disability is often associated with mortality. For this analysis, we use a newly devised extension of the model that allows for joint estimation of disability trajectories and probabilities of dropping out due to mortality (Haviland et al. 2011). In this formulation, probabilities of group membership and dropping out are no longer assumed to be independent, as is the case for the basic group-based trajectory model discussed above and for growth-curve modeling in which dropping out is treated as missing at random. Estimated mortality probabilities are instead specific to the disability trajectory group. We believe that this feature of our analysis is important, given the likely close relation of the time path of disability and the probability of dying.

Methods

Data

We use data from four waves (1998, 2000, 2002, and 2005) of the Chinese Longitudinal Healthy Longevity Survey (CLHLS), the most extensive longitudinal data set available for analyzing disability among older adults across China. Focusing

on those aged 80 and older at baseline, the CLHLS made considerable effort to verify age of respondents. Because quality of age reporting is poor or uncertain among ethnic minorities, the CLHLS included 22 of 31 Chinese provinces with few minorities, which represent 85% of the population, or more than 1 billion people. Sampling involved the random selection of 50% of counties and cities in each of the 22 provinces. Interviewers attempted to reach every centenarian in these locales (including those in institutions). For each centenarian, one octogenarian and one nonagenarian living nearby were interviewed. Approximately equal numbers of males and females were interviewed in each age decade, resulting in oversampling of males and the extremely old. Weights were calculated to match the age-sex-residence distribution of the population aged 80 and older in the 22 provinces in 1998 (Zeng et al. 2001), and these weights are incorporated at each stage of our analysis.

The current study limits the sample to those aged 80 to 94 at baseline. Those at the very upper ages are subject to extremely high and varying levels of disability. Moreover, very high rates of mortality at age 95 and older means that too few baseline respondents at those ages survive for even a second observation, let alone the completion of four waves of the survey. The combination of high and varying disability and mortality results in unstable estimates. Thus, our preliminary analyses suggested that trajectory groups for individuals aged 95 and older at baseline were determined by an increasingly small set of survivors, and the likelihood that outlying observations obscured underlying trajectories was high.

The CLHLS allowed proxy respondents to answer some or all questions. Given that age and health problems preventing responses are strongly associated, reliance on proxies increased with age of interviewees. For example, in 1998, 62% of those aged 80 to 89 responded fully on their own, whereas only 37% of those aged 90 to 99 did so (Gu 2007). Typically those not fully responding answered at least some questions. In our analytic sample, for the five questions about ADLs that we use, 65%–84% were answered fully by the respondent, depending on the wave; 3%–7% were answered partly by the respondent; and 12%–29% were answered fully by proxies. The number of items answered by proxies is not only quite substantial in the CLHLS, the subset of the population represented by proxies is more likely than others to have health problems. Additionally, proxies may respond to disability items in different ways than would the respondents themselves. Therefore, our models include a variable indicating whether any ADL responses for a particular respondent in a specific survey wave were answered by proxies.

Survey nonresponse rates in the CLHLS were quite low: about 4% in each wave (Gu 2007). In addition, loss to follow-up between waves was moderate in comparison with surveys of older people in the United States (Mihelic and Crimmins 1997). Specifically, at baseline in 1998, there were 5,155 respondents aged 80–94, 39 of whom were excluded from analysis because of missing disability information at one or more waves. Of the remaining baseline individuals, 602 (or 11.8%) were lost to follow-up by 2000, and an additional 1,290 were known to have died. Between 2000 and 2002, an additional 399 (or 12.4%) were lost, and 835 died. Finally, between 2002 and 2005, 228 cases (or 11.5%) were lost, and 878 died. The final sample size includes 3,887 individuals with responses in each wave or who were known to have died, and 9,130 observations of disability status. The numbers of male and female survivors at each wave are shown in Table 1.

Table 1 Weighted distribution of ADL limitation counts, mean number of limitations, and number of surviving respondents, by wave and gender (percentages, unless otherwise indicated)

		Wave			
Sex	Number of Limitations	1998	2000	2002	2005
Males	0	87.0	82.0	76.6	76.2
	1	5.6	7.8	11.4	10.6
	2	2.3	1.9	2.7	1.5
	3	1.4	2.3	2.2	3.2
	4	1.7	3.2	3.2	3.8
	5	2.0	2.7	3.9	4.7
	Mean	0.31	0.45	0.56	0.62
	Number surviving[a]	1,933	1,241	834	382
Females	0	81.9	75.8	68.3	66.1
	1	8.5	10.6	12.9	12.6
	2	3.2	3.2	4.9	5.0
	3	1.7	3.1	3.7	3.3
	4	1.7	2.3	4.6	3.6
	5	3.1	4.8	5.6	9.6
	Mean	0.42**	0.60**	0.80**	0.94**
	Number surviving[a]	1,954	1,356	938	502

[a] Number surviving is unweighted.

**$p < .01$, for gender difference in mean number of ADL limitations

Since the CLHLS includes a rare oversampling at the highest ages, it is well suited for the investigation of late-life disability trajectories in conjunction with mortality. In addition, analyses of response rates, attrition, completeness of data, consistency of data, age reporting, and reliability and validity of measures indicate that the quality of data is high (Gu 2007; Zeng et al. 2001).

Measures

Our measure of disability is the number of the following five ADLs that respondents are unable to do without assistance from others: eating, dressing, bathing, getting in or out of a bed or chair, and using the toilet. Mortality information was obtained from sample members' next of kin. Table 1 shows that average number of ADL limitations was 0.31 for males and 0.42 for females at baseline in 1998, and increased to 0.62 for surviving males and 0.94 for surviving females by 2005. This female disadvantage in disability is typical of China and other countries, as is the seemingly incongruous female advantage in survival (Kaneda et al. 2009; Nathanson 1975; Verbrugge 1989; Wolf et al. 2007). Given these differentials and the possibility that characteristics associated with disability may vary by gender, we estimated trajectory models separately for males and females.

We focused on a parsimonious set of predictors for disability trajectory group membership that reflect the earlier discussion of disability risk factors and previous studies of disability prevalence and transitions in China. We are limited by the availability of variables. For example, indicators of two key elements of the disablement process are not available: physical functioning and living environment in which particular ADLs are carried out. Self-reports of diseases are available, but it is not clear whether these reports reflect underlying health, access to medical care, or popular awareness of specific conditions, among other factors.

In our choice of predictors, we avoided including variables that are possibly influenced by the disability trajectories themselves. For example, we did not include indicators of current health behaviors or living arrangements. Changes in health behaviors (such as smoking or physical activity) may be in response to changes in health and associated disability. Although successfully carrying out ADLs may be enhanced via the emotional support derived from coresidence with an adult child, it could also be that individuals with ADL disability are more likely to coreside or move in together in anticipation of an expected, but not measured, need for help (Zimmer 2005). Moreover, for simplicity's sake and to focus on the basic elements of the already complicated joint modeling of disability and mortality probability trajectories, we did not include time-varying covariates.

Our predictors, all of which are measured at baseline, can be classified into three domains: demographic, SES, and early-life characteristics. Table 2 provides the

Table 2 Covariate distributions (weighted) at 1998 baseline by gender

Characteristics	Male	Female
Demographic Characteristics		
Mean age (years)	83.4	83.9**
Married (%)	45.3	12.8**
Rural (%)	68.7	66.9
Children ever born (number)	4.7	4.6
SES Characteristics		
Some education (%)	64.6	16.3**
Occupation (%)		
Agriculture	58.1	57.0
White collar (males)	13.6	—[a]
Housework (females)	—[a]	26.1
Other	28.3	16.9**
Early-Life Characteristics		
Hungry as a child (%)	54.6	58.4**
Did not have adequate medical service as a child (%)	16.0	17.3
Father had agricultural occupation (%)	74.7	71.2**
Sample Size, Unweighted	1,933	1,954

[a] Not applicable.

**$p < .01$, for gender differences in covariate distributions

prevalence of each. Demographic characteristics, besides age and sex, include marital status, urban/rural residence, and CEB. Unlike decisions about living arrangements, marital status decisions are typically made early in life. Not surprisingly, given the advanced ages of our sample and gender differences in mortality, the percentage of males married (45%) is much larger than that of females (13%). Urban/rural residence may change over time, but moves in response to disability onset or in anticipation of death may not be over great distances, and despite fairly high rates of rural to urban migration in China older adults are less likely to make such moves (Zhu 1998). The urban/rural distributions are similar for males and females, with about two-thirds of each living in rural areas. CEB is fixed early in life. On average, males have 4.7 CEB and females have 4.6, a difference that is not statistically significant.

In the second domain of SES, both education and occupation are determined early in life. We did not include an indicator of income, since at older ages in China, household income and economic well-being may be strongly influenced by living arrangements. More than one-third of males and 84% of females reported having received no formal education. The most common occupation before age 60 is work in agriculture. For our analysis of males, we categorize occupation as agriculture, white collar, and other. For female occupation, we use categories of agriculture, housework, and other (including white collar).

In the third domain, we have three indicators of early-life experiences. More than half of our sample reported childhood hunger, 16%–17% did not receive needed medical care in childhood, and more than 70% had fathers who worked in agriculture.

Survey responses were complete for marital status, urban/rural residence, and occupation. Thirty-nine missing CEB responses were coded as the mean for the rest of the sample. Twelve missing values for education were coded as no education. Among the early-life variables, 14 missing values for being hungry as a child were coded as not, 13 missing responses were coded as no for the variable indicating needing medical care as a child and not receiving it, and 12 missing values for father's occupation were coded as other.

The Group-Based Trajectory Model

Group-based trajectory modeling is a specialized application of finite mixture modeling (Nagin 2005). The software we use is based on the SAS downloadable procedure called Proc Traj (Jones and Nagin 2007; Jones et al. 2001). Here we use an enhanced version of the methodology that jointly estimates the outcome of interest—disability—and the probability of dropping out of observation due to mortality.

In the basic group-based trajectory model, the aim is to identify groups of individuals with statistically similar developmental patterns or trajectories. The distribution of outcome is denoted by $P(\mathbf{Y}_i|\mathbf{Age}_i)$, where the random vector $\mathbf{Y}_i$ represents individual i's longitudinal sequence of outcomes (i.e., y_{it}) and the vector $\mathbf{Age}_i$ represents individual i's age when each of those measurements is recorded (i.e., age_{it}). The group-based trajectory model assumes that the population distribution of trajectories arises from a finite mixture of unknown

order J. The likelihood for each individual i, conditional on the number of groups J, may be written as

$$P(\mathbf{Y}_i \mid \mathbf{Age}_i) = \sum_{j=1}^{J} \pi_j \cdot P(\mathbf{Y}_i \mid \mathbf{Age}_i, j; \boldsymbol{\beta}_j), \tag{1}$$

where π_j is the probability of membership in group j, and the conditional distribution of $\mathbf{Y}_i$ given membership in j is indexed by the unknown parameter vector $\boldsymbol{\beta}_j$, which determines, among other things, the shape of the group-specific trajectory. Typically the trajectory is modeled as a polynomial function of age in which the parameters of the polynomial are group-specific. That is, how the trajectory varies with age can differ across groups, unlike in growth-curve modeling. Further, the order of the polynomial describing trajectories may vary across groups. Both of these features allow for the possibility of distinctive trajectory shapes across groups.

For given group j, conditional independence is assumed for the sequential realizations of the elements of $\mathbf{Y}_i$, y_{it}, over the T periods of measurement. Thus, we may write

$$P(\mathbf{Y}_i \mid \mathbf{Age}_i, j; \boldsymbol{\beta}_j) = \prod_{t=1}^{T} p(y_{it} \mid age_{it}, j; \beta_j), \tag{2}$$

where $p(*)$ is the distribution of y_{it} conditional on membership in group j and the age of individual i at time t. For the current application, y_{it} is individual i's ADL count in period t. Because we use responses to questions about difficulty with five ADLs in the CLHLS, the ADL count ranges from 0 to 5. It is theoretically possible that if additional activity questions had been included, individuals' true ADL limitation counts would have been greater than 5. In other words, the number 5 is an artificial limit.

There are a number of possible candidate probability distributions for the specification of $p(*)$. None can be stated on theoretical grounds to be the correct distribution. Proc Traj allows two feasible options that we considered: the Poisson and the censored normal distributions. The Poisson distribution has the desirable property of being an integer count with a minimum permissible value of 0. However, y_{it} departs in many ways from a pure Poisson random variable. Our count is a count of disparate items that are not independent, and modeling the Poisson distribution may produce predicted values greater than 5, although 5 is the maximum in our analytic data set. The alternative is the censored normal distribution, which has the desirable feature of accounting for the data clusters at 0 and 5. The percentage of ADL counts at this maximum is not large, as shown in Table 1, but it is also not trivially small. Note that as the Poisson rate parameter increases, the Poisson distribution becomes approximately normal, so the choice between these two options is not a choice between polar opposites. We used the censored normal option because in various ways it fits the data better and results in more stable estimates.

Given our choice of specifying $p(*)$ to follow the censored normal distribution, the likelihood function can be filled out as follows. Let y_{it}^{*} denote a

latent variable linking measured disability, y_{it}, via a polynomial function of age of the following form:

$$y^*_{it} = \beta^j_0 + \beta^j_1 age_{it} + \beta^j_2 age^2_{it} + .. + \varepsilon_{it}, \tag{3}$$

where ε_{it} is a disturbance assumed to be normally distributed with a zero mean and a constant variance. In the censored normal model, the latent variable, y^*_{it}, is linked to its observed but censored counterpart, y_{it}, as follows. Let $S_{\min}$ and $S_{\max}$, respectively, denote the minimum and maximum possible scores on the measurement scale. The model assumes: $y_{it} = S_{\min}$ if $y^*_{it} < S_{\min}$, $y_{it} = y^*_{it}$ if $S_{\min} \leq y^*_{it} \leq S_{\max}$, and $y_{it} = S_{\max}$ if $y^*_{it} > S_{\max}$. That is, if the latent variable, y^*_{it}, is less than $S_{\min}$, it is assumed that the measured behavior, y_{it}, equals this minimum. Likewise, if the latent variable, y^*_{it}, is greater than $S_{\max}$, it is assumed that the measured behavior equals this maximum. Only if y^*_{it} is within the scale minimum and maximum does $y_{it} = y^*_{it}$. A detailed discussion of using the censored normal distribution to model development trajectories can be found in Nagin (2005).

In this application, iterative testing of our data suggested the need to consider only linear and quadratic specifications of age. Also, as discussed in Nagin (2005), the basic relationship in Eq. 3 can be expanded to include other covariates. As noted in our description of the data set, we included an indication of proxy response as a covariate. Therefore, for notational convenience, let $\beta^j X_{it}$ denote $\beta^j_0 + \beta^j_1 Age_{it} + \beta^j_2 Age^2_{it} + \beta^j_3 Proxy_{it}$

This basic model provides a predicted shape of each trajectory; an estimated proportion of the sample at baseline that is most likely to belong to each group; and for each individual, the estimated probabilities of belonging to each group, which are called the posterior probabilities of group membership. As an extension of this basic model, Roeder et al. (1999) demonstrated that it is possible to simultaneously estimate trajectory group shapes (as just detailed) and the relations of additional predictors to the estimated posterior probabilities of trajectory group membership. Estimated probability of trajectory group membership is specified to follow a multinomial logit function of covariates beyond those included in the basic model that estimates trajectory shapes and membership (i.e., besides age and proxy, other demographic and SES indicators). This modeling extension, which is incorporated into the trajectory estimation, allows for the simultaneous estimation of the parameters determining trajectory shapes and the multinomial logit parameters that predict probabilities of trajectory group membership as a function of individual-level covariates.

Further, Haviland et al. (2011) generalized the basic trajectory model to account for nonrandom attrition or dropout. For this generalization, the elements of $\mathbf{Y}_i$, y_{it}, are redefined to incorporate dropout information. As before, y_{it} equals its realized value prior to dropout. At the time of dropout and thereafter, y_{it} is designated as missing. The revised likelihood specifies the joint probability of the realized values of y_{it} prior to dropout and their missingness thereafter.

To explain, suppose subjects are measured over a total of T measurement occasions. Let $w_{it} = 1$ if individual i dropped out by $t \leq T$ and 0 otherwise; τ_i = the period $t > 1$ that individual i drops out and $T + 1$ if individual i does not drop out; and θ^j_t = the probability of dropout in period $2 \leq t \leq T$ given membership in group j.

For individuals to be in the study, they cannot have dropped out in period 1. Consequently, probability of dropout is necessarily zero in period 1 for all trajectory groups. Thus, by construction, w_{it} is dependent over time, since $w_{it} = 0$ in a given period implies $w_{it} = 0$ in prior periods. Similarly $w_{it} = 1$ in a given period implies $w_{it} = 1$ in subsequent periods. To account for dropout at $\tau_i < T + 1$ and the attendant data censoring, Eq. 2 must be altered. For each period up to τ_i for which there are data, the probability of the observed outcome given membership in group j is $p(y_{it} \mid w_{it} = 0, age_{it}, proxy_{it}, j; \boldsymbol{\beta}_j)(1 - \theta_t^j)$. Multiplying across the $\tau_i - 1$ periods prior to dropout for which there are data, the probability becomes $\prod_{t=1}^{\tau_j - 1} p(y_{it} \mid w_{it} = 0, age_{it}, proxy_{it}, j; \boldsymbol{\beta}_j)(1 - \theta_t^j)$. Finally, to account for the censoring due to dropout from period τ_i onward, this probability must be multiplied by the probability of dropout at τ_i, $\theta_{\tau_i}^j$ Thus, Eq. 2 in its more general form and with the addition of the proxy variable is

$$P(\mathbf{Y}_i \mid \mathbf{Age}_i, Proxy_i, j; \boldsymbol{\beta}_j, \theta_\tau^j) = \left[\prod_{t=1}^{\tau_i - 1} p(y_{it} \mid w_{it} = 0, age_{it}, proxy_{it}; j; \boldsymbol{\beta}_j)(1 - \theta_t^j) \right] \theta_{\tau_i}^j \quad (4)$$

Equation 4 is substituted into the right side of Eq. 1 to form the unconditional likelihood for individual i, which is maximized in the estimation procedure. The model extension allows θ_t^j to vary by and within trajectory group across time. The model also allows for specification of θ_t^j as a function of observed covariates.

In our models, the estimated ADL trajectories are based on counts of ADL limitations for those who survived and were interviewed at all four waves and for those who died at some point between the first and last waves. Those who dropped out for reasons other than mortality are treated as missing cases and are not included in the analysis. ADL counts are modeled as a function of age, with specific order of age polynomial depending on the group, and a dichotomous variable indicating any proxy responses to the ADL questions. To facilitate the search for maximum likelihood estimates, age is entered as a scaled variable that is one-tenth of its original value, so care must be taken in interpreting raw parameter estimates. In addition, given the nature of the censored normal distribution with a cluster of observations at zero, the coefficients must be additionally transformed to provide estimates of slopes of the distribution above zero. To assist in interpretation, plotted trajectories that transform parameter estimates into predicted limitation counts by age and group are provided.

Mortality is modeled as a function of age at survey wave before death using a logit distribution. Thus, the resulting mortality probabilities are not standard age-specific probabilities of dying but are probabilities of dying prior to the next survey wave based on age at the previous wave. Estimated mortality probabilities vary by disability trajectory group. So, unlike models that assume respondents lost to follow-up because of death or other reasons are missing at random, probabilities of dropout and group membership are assumed to be dependent.

Separate trajectory models are estimated for males and females. Inferences about optimal numbers of groups for each gender are made using a combination of the

Bayesian information criterion (BIC), significance of parameter estimates that describe trajectories, and judgment. The BIC, which unlike the likelihood ratio test allows for the comparison of nonnested (as well as nested) models, is calculated as follows:

$$BIC = Log(L) - .5log(n) \cdot k, \tag{5}$$

where L is the likelihood, n is the number of observations, and k is number of parameters. To find the best models, we iteratively tested numerous possibilities for both males and females, including larger and smaller numbers of groups with higher- and lower-order polynomials of age to describe each group trajectory.

Sensitivity Analyses

Despite high response rates in the CLHLS, those lost from one survey wave to the next for reasons other than death may be overrepresented by specific groups. Gu (2007) found that loss to follow-up in the CLHLS for those aged 80 and older was associated with being female, living in urban areas, having fewer social contacts, and having a disability. In our main analysis, nondecedents lost to follow-up were omitted because we could not jointly model both mortality and other survey attrition. However, we did conduct sensitivity analyses to assess the effects of excluding these individuals.

The first set of analyses included as dropouts both those who died and those who were lost for other reasons. The results of this test for both females and males indicated that the shapes of ADL trajectories and probabilities of trajectory group membership were not substantially different from the results of our main analysis that are presented below. This finding may result from the fact that mortality dropouts (n = 3,003) represent a large portion of total dropouts (n = 4,232). It could also be that the trajectories of the two types of dropouts are indeed similar. For our second sensitivity test, we estimated models that excluded all dropouts. The results of this were very different in terms of trajectory shapes and probabilities of group membership from the results of our main analysis. In particular, for females, some of the most severe disability experience was not manifested; and for males, smaller proportions followed the higher disability trajectories. These results suggest, not surprisingly, that the disability experiences of people who were successfully interviewed at all waves are milder than those of decedents and those of all dropouts taken together. Finally, a third sensitivity test included only the nonmortality dropouts. For both males and females, the estimates of the probabilities of dropping out were quite imprecise, and the trajectory shapes and probabilities of group membership differed considerably from those presented in this article. Overall, they exhibited less disability.

These sensitivity analyses taken together suggest that decedents experienced greater disability than either survivors or nondecedent dropouts. Given these sensitivity results, the predominance of decedents among dropouts, the current limitation of our methodology, and the inherent interest in mortality as an outcome in late life, we chose for the analysis presented here to model dropout solely due to mortality.

Results

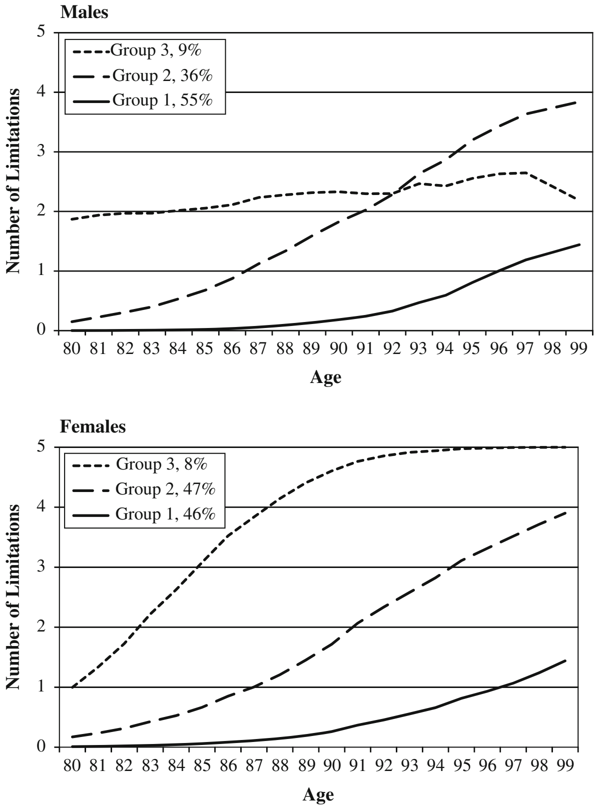
Our assessment of numerous specifications of the models, including those that involved quadratic functions of age, indicated that a three-group model best fit the data for males. Results are presented in the top panel of Table 3. As noted earlier, for computational reasons, age is treated as a scaled variable, and coefficients from censored normal models typically are not easily interpretable. Nonetheless, the direction and significance of the coefficients presented in the table can be assessed. Age is significantly, positively, and linearly related to ADL counts for the first two groups, as is proxy response for all three. Mortality also is a positive function of age, although only at $p = .069$ for group 3.

To better understand the relation of age to our outcome, we transform the coefficients and plot predicted ADL limitation count trajectories by chronological age. As shown in the top panel of Fig. 1, male trajectory group 1 best represents 55% of the weighted baseline sample; it is characterized by a level of disability that begins with no limitations at the younger ages and rises gradually beginning at

Table 3 Maximum likelihood estimates for ADL limitation count trajectories using a censored normal distribution and mortality probability trajectories using a logistic distribution by gender (standard errors in parentheses)

	Description of Disability Trajectory by Age		
	Starting Low and Rising Gradually, Group 1	Starting Low and Rising Quickly, Group 2	Starting Moderate and Remaining Stable, Group 3
Males			
Percentage in group	55.0	36.2	8.8
ADL count trajectory estimates			
Intercept	−10.24 (1.10)	−4.35 (0.61)	1.09 (0.62)
Age scaled	5.38 (0.66)	4.70 (0.72)	—
Proxy	2.33 (0.46)	2.93 (0.41)	5.02 (0.84)
Mortality probability estimates			
Intercept	−1.60 (0.16)	−1.27 (0.22)	−0.65 (0.48)
Age at last survey wave scaled	1.13 (0.16)	1.72 (0.35)	2.36 (1.30)
BIC = −6,089.1			
Number of observations = 4,390			
Females			
Percentage in group	45.6	46.6	7.8
ADL count trajectory estimates			
Intercept	−8.23 (0.91)	−4.51 (0.55)	−0.99 (1.11)
Age scaled	4.00 (0.52)	4.52 (0.48)	7.96 (4.25)
Proxy	2.01 (0.42)	2.88 (0.41)	3.51 (1.46)
Mortality estimates			
Intercept	−1.78 (0.23)	−1.62 (0.26)	−0.77 (0.44)
Age at last survey wave scaled	0.98 (0.21)	1.49 (0.25)	2.29 (1.32)
BIC = −7,329.1			
Number of observations = 4,740			

Fig. 1 Predicted number of ADL limitations by age, group, and gender (adjusted for proxy response)



around age 90 to about 1.5 limitations by age 99. Male group 2, which represents 36% of the sample, also begins at age 80 with limited disability, but the count increases much more rapidly with age than for group 1 to more than 3.5 by age 99. Male group 3 is the smallest, at 9%, and is characterized by a stable pattern of two to three ADL limitations from age 80 onward. Group 2 begins with a lower ADL count than group 3, but because of group 3's stable pattern and group 2's upward trajectory, the trajectories of the two groups cross in the early 90s.

The lower panel of Table 3 presents group estimation results for females. As for males, a three-group model best fits the data. Linear age terms are statistically significant for all three groups in the ADL and mortality estimation (although only at $p = .082$ for mortality in group 3), as is proxy response for ADLs. As shown in the bottom panel of Fig. 1, female groups 1 and 2 follow ADL trajectories similar to male groups 1 and 2, respectively. Forty-six percent of females belong to group 1, as opposed to 55% of males. More females than males are in their respective second groups. However, the difference in these percentages is not statistically significant. The ADL trajectory for female group 3, representing 8% of the female baseline sample, begins with moderate disability, approximately one limitation; the number of disabilities increases sharply, so that by about age 90, the ADL count approaches 5. This group represents the most severe disability group among all groups for both genders.

Fig. 2 Predicted probability of dying prior to next wave by age at previous wave by group and gender

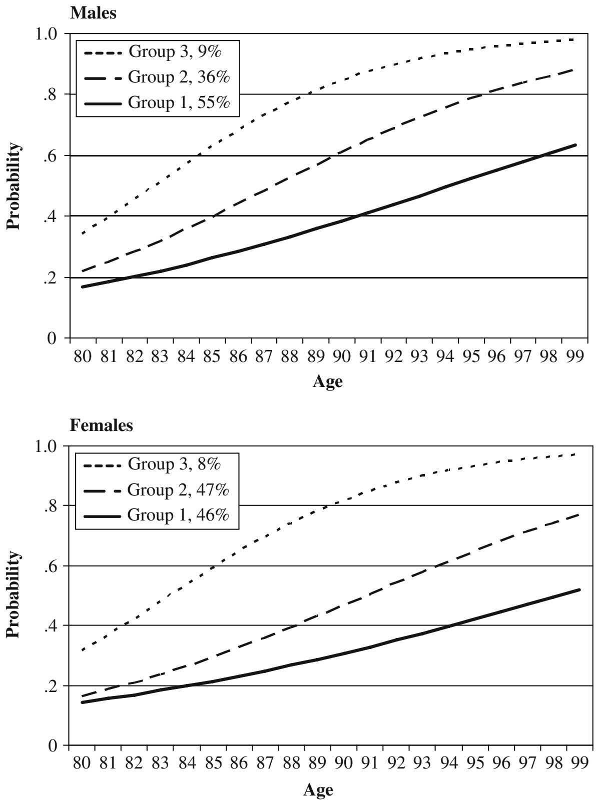


Figure 2 plots the predicted mortality probabilities by age for males (top panel) and females (bottom panel). For both, mortality probability trajectories follow the same general hierarchy as the ADL counts at age 80 for each group. Group 1 is the lowest at all ages, group 2 is in the middle, and group 3 is the highest. For group 3 among both males and females, survival to the following survey wave is extremely rare above age 95. In general, the probabilities of dying for females are lower than those for males, which is consistent with the lower overall mortality of females.

Thus far, we have provided broad interpretations of trajectories based on predicted values. Underlying each of the plotted trajectories is a multitude of individual trajectories. As with any analysis, there is uncertainty around model-based point estimates. Table 4 presents values of the upper and lower limits of the 95% confidence intervals for predicted ADL trajectories by gender, group, and age. For groups 1 and 2, for males and females, confidence bands widen with age, as mortality increases, and as the number of cases on which the trajectory patterns are based declines. The band around the much smaller male group 3 is fairly wide and more constant. The band for the much smaller female group 3 is especially wide at the earlier ages, as high as 5.0 ADLs at ages 85 and 86. Moreover, although for males the model presented here was obviously superior to all others, the choice of best-fitting model for females was not as clear-cut.

To further assess the correspondence of our models with the data, we carried out two diagnostic tests suggested by Nagin (2005) that utilize each individual's posterior probabilities of group membership. One indicator of model adequacy is that the

Table 4 Predicted number of ADL limitations and 95% confidence intervals by age, group, and gender

Age	Group 1			Group 2			Group 3		
	Predicted	Lower Limit	Upper Limit	Predicted	Lower Limit	Upper Limit	Predicted	Lower Limit	Upper Limit
Males									
80	0.00	0.00	0.05	0.15	0.00	0.52	1.87	0.39	3.34
81	0.00	0.00	0.08	0.23	0.00	0.60	1.94	0.48	3.39
82	0.00	0.00	0.11	0.31	0.00	0.70	1.97	0.52	3.42
83	0.01	0.00	0.15	0.40	0.01	0.81	1.97	0.52	3.42
84	0.01	0.00	0.19	0.53	0.07	1.01	2.02	0.58	3.45
85	0.02	0.00	0.24	0.68	0.13	1.23	2.05	0.63	3.48
86	0.04	0.00	0.29	0.87	0.20	1.55	2.11	0.70	3.52
87	0.06	0.00	0.39	1.12	0.37	2.39	2.37	1.04	3.70
88	0.09	0.00	0.38	1.34	0.37	2.30	2.28	0.92	3.64
89	0.13	0.00	0.43	1.59	0.48	2.70	2.32	0.97	3.66
90	0.19	0.00	0.47	1.83	0.56	3.10	2.33	0.98	3.67
91	0.24	0.01	0.53	2.02	0.63	3.42	2.30	0.94	3.65
92	0.33	0.04	0.62	2.28	0.70	3.87	2.30	0.94	3.65
93	0.47	0.14	0.80	2.63	0.93	4.34	2.47	1.16	3.77
94	0.59	0.21	0.97	2.87	1.03	4.70	2.43	1.11	3.74
95	0.81	0.28	1.33	3.20	1.35	5.00	2.55	1.28	3.83
96	1.00	0.34	1.67	3.43	1.61	5.00	2.63	1.38	3.88
97	1.19	0.39	1.98	3.63	1.84	5.00	2.65	1.40	3.89
98	1.31	0.41	2.22	3.74	1.94	5.00	2.42	1.10	3.74
99	1.44	0.37	2.51	3.84	2.17	5.00	2.19	0.80	3.57
Females									
80	0.01	0.00	0.19	0.17	0.00	0.49	1.00	0.00	2.58
81	0.01	0.00	0.23	0.24	0.00	0.59	1.34	0.00	2.96
82	0.02	0.00	0.27	0.31	0.00	0.71	1.72	0.00	3.55
83	0.03	0.00	0.32	0.43	0.00	0.89	2.22	0.00	4.62
84	0.04	0.00	0.34	0.53	0.04	1.03	2.62	0.00	4.87
85	0.06	0.00	0.38	0.66	0.08	1.25	3.08	0.00	5.00
86	0.08	0.00	0.42	0.85	0.13	1.57	3.52	0.03	5.00
87	0.11	0.00	0.44	1.00	0.20	1.81	3.84	0.34	5.00
88	0.15	0.00	0.47	1.21	0.28	2.13	4.14	1.11	5.00
89	0.20	0.00	0.50	1.45	0.40	2.50	4.41	1.96	5.00
90	0.26	0.00	0.54	1.72	0.57	2.86	4.60	2.76	5.00
91	0.37	0.08	0.65	2.07	0.85	3.29	4.76	3.09	5.00
92	0.45	0.16	0.75	2.33	1.05	3.62	4.85	3.00	5.00
93	0.56	0.20	0.91	2.58	1.28	3.88	4.91	2.82	5.00
94	0.66	0.26	1.06	2.82	1.50	4.15	4.94	2.92	5.00
95	0.81	0.30	1.33	3.11	1.80	4.42	4.97	3.19	5.00
96	0.93	0.34	1.53	3.31	2.01	4.61	4.99	3.59	5.00
97	1.07	0.38	1.76	3.52	2.24	4.79	4.99	3.96	5.00
98	1.24	0.41	2.07	3.71	2.51	4.92	5.00	4.28	5.00
99	1.44	0.45	2.42	3.90	2.80	4.96	5.00	4.49	5.00

average posterior probabilities of membership in group *j* for all individuals who are most likely to belong to that group should exceed .70. This standard is met for both our male and our female models; the six means range from .73 to .77. A related diagnostic is that the proportions of the sample assigned to the various groups on the basis of their highest posterior probabilities of group membership be about equal to the proportions that are generated by the maximum likelihood procedure. For males, the former are 72%, 24%, and 3%, and the latter (as shown in Table 3 and the figures) are 55%, 36%, and 9%, respectively, for groups 1, 2, and 3. For females, the comparison is 54%, 42%, and 4% versus 46%, 47%, and 8%. By this criterion, our models' performances were less successful than we would have liked, especially for males, but they are acceptable.

Table 5 presents the multinomial logit model that relates individual-level covariates to posterior probabilities of trajectory group membership. The model was simulta-

Table 5 Coefficients (log odds ratios) from multinomial logit models of group membership by gender (standard errors in parentheses)

	Demographic Model		Socioeconomic Model		Early-Life Model		Full Model	
	Group 2 vs. Group 1	Group 3 vs. Group 1	Group 2 vs. Group 1	Group 3 vs. Group 1	Group 2 vs. Group 1	Group 3 vs. Group 1	Group 2 vs. Group 1	Group 3 vs. Group 1
Males (sample size = 1,933)								
Demographic characteristics								
Married	−0.180	0.427					−0.216	0.481
	(0.361)	(0.453)					(0.451)	(0.621)
Rural residence	−0.344	−0.648					−0.195	−0.562
	(0.267)	(0.414)					(0.303)	(0.438)
Children ever born	−0.000	−0.078					0.004	−0.083
	(0.053)	(0.075)					(0.055)	(0.081)
SES characteristics								
Has any education			−0.211	0.882			−0.146	1.050[†]
			(0.264)	(0.537)			(0.296)	(0.631)
Occupation agriculture (comparison)			—	—				—
Occupation white collar			0.673	0.413			0.567	0.181
			(0.469)	(0.446)			(0.715)	(0.577)
Occupation other			0.514[†]	−0.064			0.465	−0.238
			(0.273)	(0.515)			(0.351)	(0.656)
Early-life characteristics								
Was hungry as a child					0.231	0.542	0.347	0.448
					(0.232)	(0.401)	(0.254)	(0.398)
No adequate medical service as child					0.451	0.211	0.425	0.124
					(0.297)	(0.545)	(0.324)	(0.674)
Father had agricultural occupation					−0.158	0.034	0.019	0.614
					(0.255)	(0.439)	(0.342)	(0.614)
Constant	−0.085	−1.381	−0.559	−2.533	−0.522	−2.244	−0.658	−2.928
$\Delta\ \chi^2$	16.4**		21.4**		12.4**		47.0**	

Table 5 (continued)

	Demographic Model		Socioeconomic Model		Early-Life Model		Full Model	
	Group 2 vs. Group 1	Group 3 vs. Group 1	Group 2 vs. Group 1	Group 3 vs. Group 1	Group 2 vs. Group 1	Group 3 vs. Group 1	Group 2 vs. Group 1	Group 3 vs. Group 1
Females (sample size = 1,954)								
Demographic characteristics								
Married	−0.195	0.469					−0.377	0.434
	(0.363)	(0.514)					(0.374)	(0.563)
Rural residence	−0.616**	−0.115					−0.645**	0.141
	(0.203)	(0.427)					(0.246)	(0.531)
Children ever born	−0.084*	0.094					−0.079†	0.103
	(0.038)	(0.068)					(0.041)	(0.102)
SES characteristics								
Has any education			0.314	−0.248			0.559	−0.200
			(0.358)	(0.489)			(0.392)	(0.721)
Occupation agriculture (comparison)			—	—			—	—
Occupation other			0.060	0.670			−0.044	0.782
			(0.301)	(0.436)			(0.339)	(0.646)
Occupation housework			0.770**	0.625			0.673*	0.642
			(0.269)	(0.496)			(0.297)	(0.602)
Early-life characteristics								
Was hungry as a child					0.083	0.117	0.206	0.270
					(0.255)	(0.345)	(0.293)	(0.571)
No adequate medical service as child					0.098	0.414	0.262	0.242
					(0.452)	(0.497)	(0.361)	(0.646)
Father had agricultural occupation					0.286	−0.302	0.571*	−0.062
					(0.231)	(0.376)	(0.289)	(0.413)
Constant	0.659	−2.573	−0.321	−2.159	−0.313	−1.679	−0.269	−3.321
$\Delta\ \chi^2$	27.8**		23.4**		6.6†		60.2**	

Note: $\Delta\ \chi^2$ indicates change in chi-square for the total model in comparison with the model with constant only.
† $p < .10$; * $p < .05$; ** $p < .01$

neously estimated with the trajectories themselves. Columns indicate different models including variables entered separately from the three domains—demographic, socioeconomic, and early life—followed by a full model. For all models, membership in group 1, that with the fewest ADL limitations, is designated as the contrast category. Thus, for both male and female models, we are comparing the probabilities of membership in groups that have less favorable trajectories with the probability of membership in the group that has the most favorable trajectory. Unless noted otherwise, the results we highlight are significant at the $p < .10$ level or lower.

In the male domain-specific models, only prior occupation in the military, service, or manufacturing sectors as opposed to agricultural occupation is positively associated with

group 2 versus group 1 membership. In the full model, having received at least some education is positively associated with group 3 versus group 1 membership. Such was also the case in the domain-specific model, but without statistical significance of $p < .10$. In the female domain-specific models, rural residence and a larger number of CEB are negatively associated with probability of membership in group 2 versus group 1; and housework, as opposed to agricultural work, is positively associated with group 2 membership. In the full model for females, all the aforementioned variables remain significant. In addition, having had a father who worked in agriculture is positively associated with group 2 versus group 1 membership.

Discussion

We used a group-based modeling approach for our examination of disability trajectories among the oldest-old in China, and we modeled trajectories jointly with mortality probabilities. We categorized both male and female experiences by three trajectory groups. Not surprisingly, nearly all the oldest-old in China are represented by ADL trajectories of increasing limitations with age. However, the pace varies across groups. The most favorable group for males and females is one that can be described as starting with a low level of disability that rises gradually with age. For other groups, rates of disability either rise faster or begin at a higher level. *At this aggregated level, there is no evidence of a pattern of improvement in functioning and no evidence of a pattern of remaining free of disability beyond about age 90.* One small group of males, which begins at age 80 with several ADL limitations, shows no increase in disability with age. Also, for each gender, the level and pace of increase by age of predicted mortality probabilities are hierarchically related by group to the estimated number of ADL limitations at age 80. Generally, oldest-old Chinese females appear to experience less favorable ADL trajectories than males, but lower probabilities of mortality.

Significant associations of individual characteristics with probabilities of trajectory group membership are more numerous for females than males, but even among females, they are few. It could be that at the ages considered here, influences of unobserved biological factors outweigh those of the included measures. For instance, sociodemographic associations with trajectory group membership were not very strong, but advancing age may have leveled differences that existed earlier. Indeed, the results of our models of characteristics associated with group membership may be influenced by mortality in two important ways: possible survival of the fittest among those who might otherwise be considered most disadvantaged and, among a small select group (males in group 3), possible expansion of morbidity (as opposed to the compression hypothesized by Fries (1980)). Regarding the former, not only does age appear to be a leveler of functioning advantage that might be associated in earlier life with factors such as urban residence or employment in a nonagricultural occupation, but also it seems that there may be a crossover of sorts so that what might be considered a disadvantage becomes positively associated with continued functioning and avoidance of disability for the very old. Notably, for both males and females, having had an agricultural occupation is associated with likely membership in the

most favorable trajectory (group 1) as opposed to the less favorable trajectory (group 2). Agricultural workers likely engaged in more demanding physical activities and were exposed to greater hazards on the job. In addition, for females, rural residence is associated with greater likelihood of membership in group 1 versus group 2. Current rural residence is likely correlated with lifetime rural residence and its associated health disadvantages (e.g., the rural-urban difference in mortality associated with the Great Leap Forward Famine of 1959–1961; see Lardy 1987). The mortality selection interpretation suggests that those who endured such hardship early in life and survived tend to be less frail in old age. In contrast, for females, having had a father who worked in agriculture is associated with membership in a less favorable trajectory, which is inconsistent with this interpretation, but may reflect long-lasting effects of lower standards of living and fewer opportunities that were not necessarily fatal but debilitating.

Male group 3 appears to represent quite a distinctive population. Males who received at least some education are more likely to be members of this small group, whose ADL trajectory has the highest predicted value at age 80—more than two ADLs—but remains flat as age increases. Although experiencing ADL limitations, they may be somewhat privileged through the benefits of their education. Earlier research has suggested that education also predicts survival to these advanced ages (Liang et al. 2000). Thus, it is possible that some more-privileged males in China are currently experiencing an extended period of survival although in a disabled state. Note, however, that although these individuals may be more likely to survive to age 80, the mortality probabilities shown here suggest relatively high chances of dying at very old ages.

Having borne more children appears to be protective for females in old age. The mechanisms through which it operates—genetic, biological, or social—remain unclear. Recent research in China has suggested that living with children is not necessarily the most advantageous arrangement for late-life functioning (Li et al. 2009), which would argue against the social mechanism. The fact that the relation does not hold for males suggests that if there is a social mechanism, it is more important for females. Alternatively, it could be that there is indeed a biological element at work.

Our study has limitations. First, we relied on self- or proxy reports of disability rather than more objective tests of functionality. Still, self-reports of disability have been found to be predictive of nursing home placement and mortality (Reuben et al. 2004). In addition, for the CLHLS, the ADL and other health measures show good internal consistency and construct validity (Gu 2007). Second, although the methodology we used summarizes a great deal of information and complexity represented by the multiplicity of individual trajectories, the confidence intervals surrounding the predicted trajectories are at times wide. There is no doubt that diminished sample sizes at the highest ages and in the smallest groups played a role. Third, the analysis does not take into account the possibility of cohort effects, which might reflect selective survival to a particular age (and thus inclusion in the survey) or, more generally, different life experiences of age subcohorts. In essence, we have taken the synthetic cohort approach that demographers frequently use—that is, combining the experiences of multiple smaller subcohorts to estimate how experience may vary across a wide range of ages, across which no single cohort is actually fully observed. Our seven-year observation period produces considerable

overlap in our age subcohorts, but in future work, we plan to investigate the sensitivity of our results to cohort effects.

Other possibilities for future refinements and expansion of our analysis include modeling other specifications of the ADL outcome—for example, a dichotomous form; investigating time-varying covariates; and examining other disability outcomes, such as limitations in physical functions and IADLs. In particular, future work might productively apply this group-based modeling strategy to health trajectories at younger ages at which mortality is lower, recovery is more common, and group membership is perhaps more strongly associated with measurable characteristics of individuals.

The methodology that we employed in the current study could be easily applied to other areas of interest to demographers—for example, the study of poverty, wages, employment, and marital status. In the case of poverty, longitudinal data provide important insights into the dynamics of moving into and out of poverty. However, the poorest individuals may be most likely to be lost to follow-up, and the poverty histories of those who are observed at all waves of a survey may be different from those who drop out. Thus, the outcome indicator, poverty, and the loss to follow-up may be dependent.

But foremost, we hope that the analysis presented here has demonstrated the value of the group-based trajectory methodology for modeling the dynamic nature of disability *jointly with mortality*. As shown in the sensitivity analyses, limiting the analysis to survivors would have resulted in substantially different disability trajectories that do not truly reflect the experience of the entire population up until death. The trajectories shown in our tables and figures indicate more severe disability experiences that should be considered in the development of programs and policies for older people in China.

Acknowledgments The current research was assisted by a grant from the National Institutes of Health–National Institute on Aging, Grant No. 1R21 AG036938-01, "Modeling Disability Trajectories in Rapidly Aging Population." The authors thank Douglas A. Wolf for his thoughtful comments on an earlier version of this article, Danan Gu for providing insight into the CLHLS data set, and two anonymous reviewers. An earlier version of this article was presented at the annual meeting of the Population Association of America, Detroit, Michigan, April 30–May 2, 2009.

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