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Examining Late-Life Functional Limitation Trajectories and Their Associations With Underlying Onset, Recovery, and Mortality

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Objectives. Identify common trajectories of physical functional limitation and mortality among Taiwanese 50 and older as they age, link these to underlying transitions in onset, recovery, and mortality, and assess associations between trajectories and a set of risk factors.

Method. Longitudinal data from 4 waves of the Survey of Health and Living Status of the Middle-Aged and Elderly in Taiwan, collected between 1996 and 2007, are analyzed using a summary measure indicating difficulty with one or more of 7 physical functions. A group-based trajectory model identifies common trajectories. Shorter term transition probabilities that underlie multiperiod trajectories are examined. Multinomial regression associates risk factors with trajectory group membership.

Results. Best fitting the data is a model with 3 groups characterized as early, mid, and late onset of limitation. Roughly half the population follows the trajectory of mid onset and a quarter each of the other 2. Females and those least educated are most likely to belong to the early-onset group.

Discussion. The analysis advances understanding of late-life functioning by focusing on the heterogeneity of functional limitation experience, appropriately accounting for the relation between functional limitation and mortality and linking long-term patterns with short-term changes in functional limitation.

Key Words: Demography—Disability—Epidemiology—Functional health status.

Introduction

Recent research has highlighted trends in late-life functional and activity limitations among older Taiwanese. The observed changes depend on the periods of observation and measures examined, but on balance prevalence rates of limitation appear to have gone down or remained stable (Martin, Zimmer, & Hurng, 2011). Due to rapid fertility and mortality decline, the proportion of Taiwanese 50 and older is expected to climb steadily from 32% in 2012 to more than 53% by 2040 (Council for Economic Planning and Development, 2012). Thus, even with decline in age-specific prevalence of limitation, population aging will likely result in increases in the overall number of people with limitations.

A small number of studies of physical functioning transitions across two periods of time have been conducted for Taiwan and other East Asian populations (Beydoun & Popkin, 2005; Chang & Zimmer, 2006; Gu & Zeng, 2004; Liang, Liu, & Gu, 2001; Liu, Liang, Muramatsu, & Sugisawa, 1995; Zimmer, Liu, Hermalin, & Chuang, 1998). These analyses have advanced understanding of short-term transitions. But to better understand the process of individual limitation, it is useful to conduct multiperiod longitudinal analysis that allows for the characterization of the many possible transition patterns that occur as people age (Wolinsky, Armbrecht, & Wyrwich, 2000). Such analysis requires the availability of high-quality panel data and a technique for summarizing the multitude of possible limitation patterns that can occur over time. With the exception of one study that used hierarchical linear modeling to examine the average change in functioning (Liang et al., 2010), such analysis has not been done for Taiwan. Also challenging is the need to consider survival in conjunction with limitation. As Murphy et al. (2011) note, death is not unrelated to outcomes of interest in gerontological research, and functional limitation is a prime example.

One approach to longitudinal analysis of late-life limitation has been to estimate separate trajectories for survivors and decedents (Li, 2005). Another has been to add survival status as part of a trajectory equation (Liang et al., 2010; Yang & Lee, 2010). These approaches are limited in that survival is neither independent nor a predictor of limitation. The current study applies a group-based modeling approach that allows for the joint estimation of trajectories of limitation and mortality (Haviland, Jones, & Nagin, 2011). This technique has the added advantage of allowing investigation

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of the heterogeneity of the limitation experience by estimating a number of common patterns rather than focusing on the average for the entire population.

The first major application of joint group-based trajectory modeling of limitation and mortality examined counts of inability to conduct activities of daily living (ADLs) among Chinese aged 80+ (Zimmer, Martin, Nagin, & Jones, 2012). Results indicated that male and female populations can each be grouped into three typical multiperiod patterns of ADL limitation. These patterns differ by rate of increase in the number of ADL limitations from age 80 and older with the exception of one group of males whose count of ADL limitations is flat with advancing age. No group pattern exemplifies a recovery from ADL disabilities. Mortality trajectories map ordinally to disability trajectories with those with the highest ADL trajectory having the highest mortality trajectory.

The study cited above focused on the most severe type of limitation among a very old population. Trajectories of late-life limitation may vary depending on the indicator of limitation used, the age group studied, and the life experiences of the population. In the stylized representation of disability known as the disablement process, pathologies (e.g., arthritis) may result in impairments (e.g., joint stiffness), which are subsequently expressed as limitations in cognitive, sensory, and physical functioning (e.g., trouble stooping; Nagi, 1965; Pope & Tarlov, 1991; Verbrugge & Jette, 1994). Disability in activities (e.g., bathing) represents not only the functional limitation but also the nature of the activity and the physical and sociocultural environment in which it is being carried out. Given interest in delaying or preventing onset of disability within rapidly aging societies, it is useful to focus on measures that are less influenced by environmental factors and reflect earlier stages of the process, such as functional limitations (Guralnik & Ferrucci, 2003; Kingston et al., 2012). Physical functional limitations are more common among middle-aged people than are ADL limitations, and investigating their trajectories beginning in late middle age may provide insight into the developmental course of late-life limitation. Examining the process as it unfolds from late middle ages onward facilitates discrimination between high- and low-functioning people at an early stage and provides opportunity for identifying targets for intervention to prevent onset and progression to later and more severe stages of the disablement process.

The current study focuses on how functional limitation is manifested over time at the individual level using a longitudinal sample of Taiwanese ages 50 years and older with three specific analytical aims. The first is to identify common trajectories of the probability of functional limitation, modeling them jointly with the probability of dying. The common trajectories depend on patterns of transitions that take place at the individual level, including the probability of onset and progression of and recovery from functional limitation, as well as the probability of survival. Higher probability of onset and lower probability of recovery translate into less-favorable long-term functional limitation trajectories. Higher survival among those with functional limitation is associated with less-favorable trajectories, whereas survival among those without limitation translates into favorable patterns. Therefore, to gain insight into the meaning of these trajectories for underlying experiences of onset, recovery, and mortality, the second aim of this analysis is to investigate the link between multiperiod trajectories and period-to-period transitions for different trajectory and broad age groups. The third aim is to test associations between trajectory group membership and several individual socio-demographic characteristics often associated with functional limitation.

Method

Data

Data are from the Survey of Health and Living Status of the Middle-Aged and Elderly in Taiwan. This longitudinal panel began in 1989 with a random representative sample of 4,049 individuals living in the community or institutions aged 60+. The original survey was carried out by the Taiwan Provincial Institute of Family Planning (now the Bureau of Health Promotion) in conjunction with the University of Michigan and with support from the Taiwan government and the U.S. National Institute on Aging (Chang & Hermalin, 1989).

Individuals (or proxies in cases of individuals unable to respond for health reasons) were interviewed in their homes. Survivors (or their proxies) were reinterviewed in 1993, 1996, 1999, 2003, and 2007. In 1996 when the original cohort was aged 67 and older, a new cohort aged 50–66 was added, providing a representative sample aged 50 and older. The data used for the current study include waves 1996, 1999, 2003, and 2007. Therefore, as far as this study is concerned, individuals are first observed in the year 1996, and at time of first observation, they may be of any age from 50 and older. The reason we begin the observation of individual trajectories in 1996 is that there were differences in wording of functional limitation questions prior to 1996.

Our 1996 baseline includes 5,131 individuals 50 and older who are either survivors to 1996 from the original 1989 cohort or newly sampled in 1996. Response rates for all waves are very high. If a respondent was missing for one wave, attempts were made to contact and interview that person for a following wave. This aspect of the survey coupled with high response rates means that overall nonmortality attrition is low. Of 5,131 cases at baseline, 3,024 were alive and interviewed in 2007, 1,829 had died prior to 2007, and 278 (5% of baseline cases and 8% of the 2007 surviving sample) were alive but lost to follow-up in 2007. Deaths were determined through linking data with very accurate administrative records on mortality. Weights are provided to assure that the total sample combining the 1989 and 1996 cohorts is representative of Taiwan's 50

and older population as of 1996. Over the years, these data have been used in numerous health-related analyses (some notable examples include Glei et al., 2005; Goldman, Lin, Weinstein, & Lin, 2003; Hermalin, 2002; Liu, Hermalin, & Chuang, 1998).

Outcome Measures

Survey respondents were asked: "If no one helps you and you have no aids to help you, will you have trouble doing the activities below by yourself?" The seven functions that followed were raising hands over head, grasping or turning objects with fingers, lifting or carrying something weighing 11–12 kg such as two pecks of rice, standing for 15 min, squatting, running a short distance such as 20 or 30 m, and walking up two or three flights of stairs. Cronbach's alpha for the interclass correlation of these seven functions is .870 (95% confidence interval [CI]: 0.865–0.876) indicating good reliability. Respondents were coded as having a functional limitation if they reported having difficulty doing any one of these tasks. In 1996, 37% of the sample reported such difficulty. Difficulty running, lifting, and squatting are the three most common limitations, and if a person has a single limitation, it is one of these three about 90% of the time.

Modeling and Analysis

There are several parts in this analysis. The first is estimation of a group-based trajectory model (GBT) for determining a discrete number of common functional limitation trajectories (Jones, Nagin, & Roeder, 2001). GBT modeling identifies clusters of individuals following similar developmental pathways by age (Nagin, 1999, 2005; Zimmer et al., 2012). The technique has been used for a variety of outcomes such as delinquency, depression, and work (Andreescu, Chang, Mulsant, & Ganguli, 2008; Kaplan, Strawbrige, Camacho, & Cohen, 1993; Liu, Lin et al., 1995). It has also been used in studies of functioning and disability (Dodge, Du, Saxton, & Ganguli, 2006; Gill, Gahbauer, Han, & Allore, 2010; Taylor, 2005). GBT modeling uses maximum likelihood to identify groups of individuals with statistically similar trajectories. Two primary outputs of the estimation are (a) shapes of trajectories of each group as specified by group-specific polynomial functions of age and (b) estimated percentages following each identified trajectory. Because this study is investigating trajectories of the probability of functional limitation by age, trajectories are modeled using a binary logistic with age as the independent variable (to facilitate model convergence, age is scaled by subtracting the mean and dividing by 10).

We first fit a base model without covariates in order to determine number of groups and the order of the polynomial functions of age that specify the trajectory for each group. Several dozen potential solutions with varying numbers of groups and orders of polynomials for the age variable were tested. We used a model-selection process described in Nagin (2005) to choose the best fitting model. The choice relies on the Bayesian Information Criterion and diagnostic tests based on posterior probabilities. A posterior probability is a postestimation calculation that assigns a numeric likelihood in the form of a probability that an individual belongs to each of the groups. For each individual, posterior probabilities across the groups sum to 1.0. The group that has the highest probability can be used as a "best guess" of the trajectory group within which an individual belongs. We further explain how these probabilities are used for model testing below.

Our application of the GBT model uses the generalization developed by Haviland and colleagues (2011) that allows joint estimation of trajectories of functional limitation, and for each trajectory group, the probability of nonrandom dropout by age. For this study, the nonrandom dropout event is mortality, which is modeled as a function of age at survey wave prior to death. Thus, under this model generalization, there is an additional output: a group-specific function describing the probability of mortality by age. One implication of allowing for nonrandom dropout due to death is that trajectory groups with relatively higher mortality rates will become proportionately smaller over time—a function of higher dropout. Thus, the probability of trajectory group membership should be interpreted as the estimation of the size of the group measured at baseline. We conduct sensitivity analyses to see how results differ if we include in our analysis only survivors, only decedents, or model together both death and loss-to-follow-up.

Next, we use each individual's assignment to a trajectory group resulting from the maximum likelihood estimation to calculate for each group the probability that an individual of a given age and functional limitation status at baseline will transition to the opposite status or die before the end of observation in 2007. These calculations allow us to comment on how functional limitation trajectories are related to underlying functional limitation transitions.

Finally, using the same specification of the best-fitting base model (number of groups and orders of age polynomials), we refit the model, and in the same maximum likelihood procedure simultaneously estimate the association of potential risk factors to membership in particular trajectory groups via a multinomial logistic regression. We tested associations with the variables whose descriptive statistics are shown in Table 1: sex, years of education, Mainlander status (whether someone migrated from Mainland China at the time of the revolution in the late 1940s), marital status, urban/rural residence, and the proportion of survey responses provided by proxy. We also explored associations with group membership of interactions between significant main effects.

Risk factors were chosen on the basis of data availability and previous studies indicating their associations with functional limitations in Taiwan (e.g., Liang et al., 2010; Martin et al., 2011; Zimmer et al., 1998). Our goal was to identify

a small number of critical covariates that well delineate the risk of physical functional trajectory group membership.

Sex, education, and Mainlander status do not change with time in late life, but marital status and urban/rural residence may change. Given 2- and 3-year intervals between survey waves, we decided not to model these as time-varying covariates because we could not ascertain temporal ordering in relation to functional limitation. We modeled their baseline values as risk factors for subsequent functional limitation trajectory group membership. We considered including other potential risk factors such as income and living arrangements, but they are more likely to be influenced by functional limitations, even at baseline. The Taiwan survey collected self-reports of some health conditions, which conceptually precede functional limitations in our framework, but these self-reports may be influenced by access to health care and health literacy and thus are not included.

We did include an indicator of proxy response, because self-respondents and proxy respondents may provide differing views of the respondent's abilities. Indeed, proxies are more likely to report limitation in some settings (Santos-Eggimann et al., 1999). Moreover, for this survey, proxy respondents were limited to cases in which the individual was unable to respond for health-related reasons. So proxy response may well be associated with membership in different trajectory groups. We tested three specifications of the proxy variable for each individual—number of waves answered by a proxy, any wave answered by a proxy, and proportion of waves answered by a proxy. Results were substantively the same for all three. Here, we report results for the last.

Table 1. Weighted Sample Characteristics (N = 5,131)

Measurement	Mean or proportion	Standard deviation
Age in 1996 (years)	63.36	9.00
Sex (0 = male; 1 = female)	0.47	0.50
Years of education	4.85	4.53
Mainlander status (0 = other; 1 = mainlander)	0.13	0.33
Marital status in 1996 (0 = not married; 1 = married)	0.75	0.43
Rural/urban residence in 1996 (0 = rural; 1 = urban)	0.66	0.47
Proportion of survey waves answered by proxy	0.08	0.22

Results

Functional Limitation Trajectories

Table 2 presents the best-fitting base model, which has three groups. Trajectories of functional limitations for groups 1 and 3 are described with an intercept and single age parameter. Group 2 is described with an intercept and linear and quadratic age parameters. Age parameters are all positive, indicating increasing probabilities of functional limitation with increasing age. In addition, although intercepts vary substantially across groups, magnitudes of the age parameters for groups 1 and 3 are very similar, suggesting consistency in the rate of increase by age in the probability of a functional limitation. For mortality, each group is modeled with an intercept and age at last survey wave. The coefficients are all significantly positive, indicating that mortality increases with age at last survey wave. The maximum likelihood estimated percentage of the population that is a member of each group at baseline indicates that groups 1 and 3 are roughly equal in size with about one-quarter of the population in each, and group 2 is the largest representing about half the population.

To further assess fit of the base model, we conducted two tests prescribed by Nagin (2005) that utilize posterior probabilities of group membership generated as part of the maximum likelihood estimation. Posterior probabilities indicate estimated chances that an individual belongs to each group. For instance, a person aged 74 at baseline, who survives to be interviewed at all waves (therefore survives to 85), who does not have a functional limitation at Waves 1 and 2, but has an onset by Wave 3 (that is, observed as having a limitation at age 81), and remains with a limitation at Wave 4, is calculated as having a 0.8 probability of belonging to group 1 and 0.2 and 0.0 probabilities of belonging to groups 2 and 3, respectively. Using such posterior probabilities, individuals

Table 2. Maximum Likelihood Logit Results for Functional Limitation and Mortality Trajectories From Base Model

	Group 1	Group 2	Group 3
	Late onset	Mid onset	Early onset
Parameters for functional limitation trajectory			
Intercept	−2.115 (.259)*	0.463 (.232)*	3.535 (.535)*
Linear scaled age	2.120 (.136)*	1.853 (.083)*	2.198 (.277)*
Quadratic scaled age	—	0.315 (.070)*	—
Parameters for mortality trajectory			
Intercept	−2.584 (.429)*	−2.029 (.202)*	−1.206 (.106)*
Linear scaled age at previous wave	1.168 (.399)*	1.438 (.248)*	0.619 (.103)*
Group size (%)	23.7	49.6	26.7
Bayesian Information Criterion = −13,256.14 (N = 5,131)			

Notes. Standard errors are in parentheses.
*p < .05.

can be assigned to groups for which their corresponding posterior probabilities are highest. These assignments may differ from the overarching assignment made as part of the maximum likelihood estimation. One test of model fit is that the average posterior probability across individuals assigned to a particular group on the basis of their posterior probabilities is 0.70 or higher. Our results indicate that the average is 0.70 for group 1, 0.71 for group 2, and 0.75 for group 3, and thus, the standard is met. A second test is that the proportions of the sample assigned to the groups on the basis of highest posterior probabilities are about equal to the proportions generated by the maximum likelihood assignments. For the base model, the former percentages are 24.8, 50.9, and 24.3, respectively, for groups 1, 2, and 3, and the latter 23.7, 49.6, and 26.7, again indicating a good fit.

Figure 1 translates estimated parameters from the base model into predicted probabilities of functional limitation by age. Note that while Figure 1 shows the trajectories up to age 95, numbers that survive to that age are small. This is, especially, the case for the first and third groups, which represent smaller proportions of the population than the larger second group. Figure 1 shows that the trajectory, regardless of group, can be universally described as continually increasing with age. Therefore, the "typical" individual within any of the groups is unlikely to escape having a functional limitation given survival to old age. At the same time, Figure 1 shows three distinct patterns, which we call "early," "mid," and "late" onset.

Table 3 presents several summary descriptors for each trajectory group: probability of a functional limitation at age 50 (row 1), ages at which the probability of a functional limitation passes various milestones (0.25, 0.50, and 0.95; rows 2–4), and ages at last wave at which the probability of dying passes 0.25 and 0.50 (rows 5–6). There are differences across groups in initial probabilities of having a functional limitation and in the ages at which the milestones are reached. Those in the late-onset group have a zero probability of a functional limitation at age 50. They reach a probability of 0.50 by age 81, and they only approach but never reach a probability of 1.00. Those in the mid-onset group have fairly low probabilities of functional limitation at younger ages, but probabilities increase at an earlier age than for the late-onset group. By age 69, they have a probability of 0.50, and by age 83, a 0.95 probability. The early-onset group already has a 0.25 probability of a functional limitation at age 50, and the probability reaches almost 0.95 at the relatively young age of 69.

Despite these differences among the groups, comparison of the time that it takes for the probability of functional limitation to increase from 0.25 to 0.95 shows that it is the same, 19 years, for both the early-onset and late-onset groups. This similarity is also suggested by the age parameters shown in Table 2, and the similar slopes of the curves in Figure 1. It is a little longer at 22 years for the mid-onset group. The years between 0.50 and 0.95 probabilities are exactly the same at 14 years across all three groups. Thus, although the typical member of the late-onset group does not develop a limitation until older age, the change from a moderate to a high probability occurs as rapidly as for the other groups with the main difference being a later age at which the increase begins.

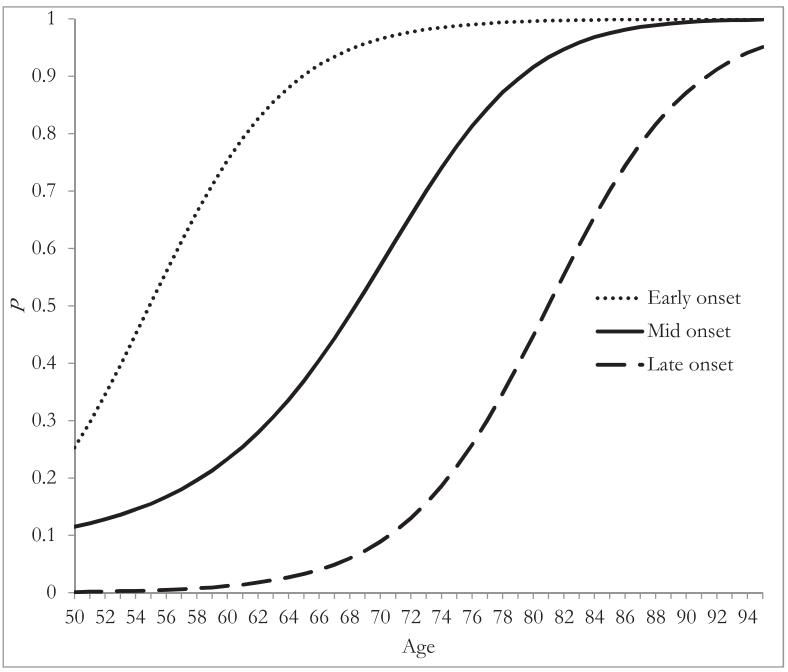

Figure 1. Functional limitation probabilities by age and group.

Probability of Death

Estimated mortality trajectories are presented in Figure 2. Probabilities of dying for the late-onset and mid-onset groups are very similar up to about age 70. From 70 to 83 years, the ranking of mortality probabilities by group is the same as the ranking of functional limitation probabilities by group. Overall, from age 50 to age 83, the early-onset group has the highest probabilities of dying. By age 83, the sample sizes become small, particularly for the early-onset group that has higher mortality up to that age. Therefore, any patterns beyond that age need to be interpreted with caution. The results shown in Figure 2 suggest the possibility of a crossover at age 83 with the probabilities of dying for the mid-onset group surpassing those of the early-onset group. The late-onset group maintains the lowest probability of dying from age 70 on. If the crossover is "real" and not a function of random error due to small numbers surviving to these ages, it could reflect several phenomena such as a robustness of those in the early-onset group who do survive, the particular diseases associated with functional limitation as opposed to with mortality, and the sex distribution of the groups.

For the late-onset group, the age at previous wave at which the probability of dying reaches 0.25 (Table 3, row 5) is 84 years, higher than the 78 years for the mid-onset group and 71 years for the early-onset group. The age pattern of reaching a probability of death of 0.50 (Table 3, row 6) follows a similar ranking. Comparison of rows 3 and 6 indicates that the late-onset group on average has 15 years between reaching a 0.50 probability of functional limitation and a 0.50 probability of dying, whereas the mid-onset and early-onset groups have 17 and 25 years, respectively. These calculations suggest that members of the early-onset group are very likely spending many more years living with a functional limitation than are members of the mid-onset and late-onset groups. Even though their mortality is highest of the three groups up to age 83, their onset of limitation is much earlier, resulting in a long period of limitation.

The importance of jointly modeling mortality and functional limitation trajectories is underscored by the three sensitivity analyses that treat dropping out in different ways (results not shown). First, when we exclude both those who died and those lost to follow-up from our analysis, that is,

Table 3. Summary Indicators of Trajectories by Group, Base Model (N = 5,131)

	Late onset	Mid onset	Early onset
1. Probability of functional limitation at age 50	0.00	0.12	0.25
2. Age at which functional limitation probability passes 0.25	76	61	50
3. Age at which functional limitation probability passes 0.50	81	69	55
4. Age at which functional limitation probability reaches 0.95	95	83	69
5. Age at previous wave at which mortality probability passes 0.25	84	78	71
6. Age at previous wave at which mortality probability reaches 0.50	96	86	80

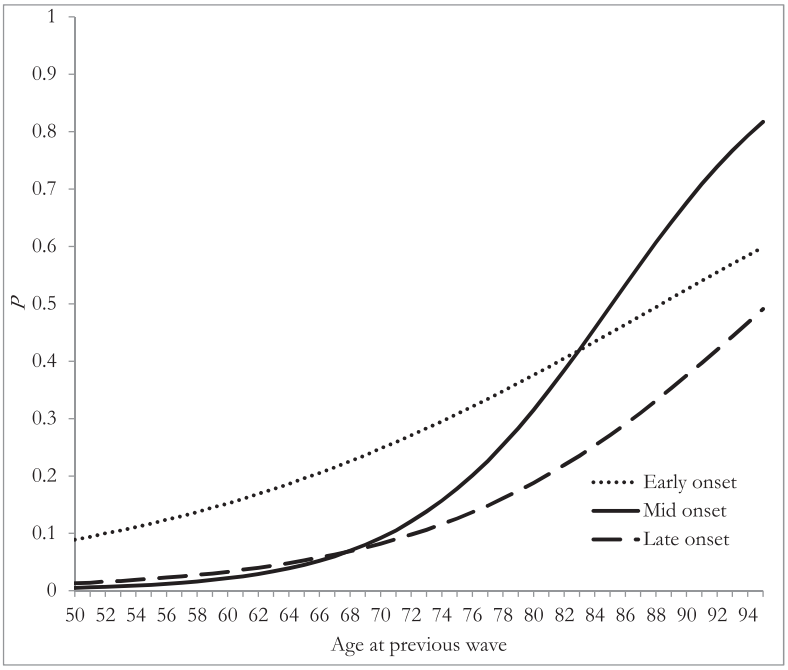

Figure 2. Predicted probability of dying prior to the next wave by age at previous wave and group.

we model trajectories only for survivors who completed all four survey waves, the results indicate slightly lower probabilities of limitation at each age for each group and higher proportions in less limited groups, suggesting that survivors have better functional limitation outcomes than decedents. Second, fitting a model only for decedents results in much higher probabilities of functional limitation. These first two tests confirm that functional limitation trajectories are not independent of survivorship. Third, we combine death and loss-to-follow-up into a single indicator of nonrandom dropping out and modeled its trajectories jointly with functional limitation trajectories. Results are similar to those of our main analysis, indicating that there is either little difference in functional limitation trajectories between the two groups or the number of nondecedent missing is so small that dropping out due to mortality dominates the analysis.

Functional Limitation Transitions Underlying the Trajectories

The trajectories described above are based on models that use data from individuals who experience a variety of transitions from wave to wave of data collection. Individual changes include stability and recovery, even though the three trajectories show that "on average" the probability of a limitation continues to increase with age. To probe the heterogeneity of experiences of individuals, we returned to the raw data and divided the sample into 12 subsamples based on age at baseline (50–59, 60–69, 70–79, and 80 and older) and group membership (early, mid, and late onset). For each of the subsamples, we determined the weighted percentage of individuals who had a functional limitation at baseline. For those who did not have a functional limitation at baseline, we determined the percentage that experienced an onset, defined as reporting a functional limitation at Wave 2 or a subsequent wave prior to dying for decedents or by the end of observation period at Wave 4 for survivors. For those who had a limitation at baseline, we determined the percentage that experienced recovery, defined as reporting no functional limitation at Wave 2 or a subsequent wave prior to dying for decedents or by the end of observation period at Wave 4 for survivors. In addition, we determined the percentage who died by baseline functional limitation status. These results are presented in Table 4 along with the unweighted sample sizes for each of the 12 groups.

Those in the late-onset group generally do not have a limitation at baseline regardless of age and therefore most in this group are not at risk of recovery, but are at risk of an onset. For example, 98.1% of those aged 60–69 at baseline in the late-onset group are at risk of onset in the second panel of Table 4, whereas only 1.9% are at risk of recovery in the third panel. Nobody aged 50–59 experiences an onset. The chances of an onset increase with age but never reach 100%. Among the very few in this group who begin with a limitation, the chance of recovery is 100%.

The members of the mid-onset group have a less than 20% chance of a functional limitation at baseline if they are first observed under age 70. ("First observed" refers to the age of individuals in what is considered the first wave of observation for this study, namely, the year 1996.) They have higher probabilities if first observed at age 70–79 and a 100% chance if first observed at 80 and older. In contrast to the late-onset group, the chances of an onset are high among those in the mid-onset group—over 80% among those first observed at ages 50–79 years. Among those who have a functional limitation at baseline, the probability of recovery is essentially 100% for those under age 70, but unlikely for those 70 and older. Therefore, recovery transitions for the mid-group are dependent on age.

Except for those who are 50–59 when observed at Wave 1, individuals in the early-onset group are very likely to have a functional limitation at baseline. If not observed with a functional limitation at baseline, they are very likely to experience an onset. They are not very likely to experience a recovery. In fact, the probability of recovery for those in the early-onset group who are first observed at age 60 and older is 2% or less.

The results for mortality generally confirm what was shown in Figure 2. The probability of dying increases with age and is highest for those in the early-onset group up until baseline age 80 and older, no matter what the limitation status at baseline. Due to small numbers surviving past age 80 in the early-onset and late-onset groups and the small numbers with limitations as baseline among the late-onset group, patterns at very old ages should be interpreted with caution.

Association of Risk Factors With Group Membership

Table 5 shows results of the multinomial logit regression predicting group membership. Three models are shown. Model 1 is a full model that includes all the risk factors we considered. Model 2 is a parsimonious model that includes only those variables that are significantly associated with group membership. Any other risk factor when added individually to this model remains insignificant. Model 3 includes the interaction between sex and education, which is the one significant interaction among the significant covariates. For each model, the comparison group is late onset, and the coefficients shown in Table 5 indicate the associations of the variables with being in the mid-onset or early-onset groups relative to being in the late-onset group.

Mainlander status, being married in 1996, and living in an urban area in 1996 are not significantly associated with group membership. In both models 1 and 2, females are much more likely than males to belong to the mid-onset and early-onset groups in comparison with the late group. Each additional year of education decreases the chances of being in the mid-onset and early-onset groups. Therefore, it is males with more education who are most likely to be

Table 4. Percentage With a Limitation at Baseline and the Percentages Experiencing Onset, Recovery, and Death, by Age at Baseline and Trajectory Group (Weighted)

	Late onset	Mid onset	Early onset
Percentage with limitation at baseline (n = 4,853)[a]			
Age 50–59	0.0	16.1	51.4
Age 60–69	1.9	19.5	96.3
Age 70–79	6.6	65.0	100.0
Age 80+	12.8	100.0	100.0
Percentage without limitation at baseline who experience an onset (n = 2,747)			
Age 50–59	0.0	84.7	80.7
Age 60–69	26.2	89.8	100.0
Age 70–79	64.4	87.6	na[b]
Age 80+	65.3	na[b]	na[b]
Percentage with limitation at baseline who experience a recovery (n = 2,106)			
Age 50–59	na[c]	100.0	30.1
Age 60–69	100.0	99.6	1.5
Age 70–79	100.0	14.8	0.0
Age 80+	100.0	0.0	0.0
Percentage without limitation at baseline who die (n = 2,747)			
Age 50–59	0.0	9.7	40.1
Age 60–69	7.8	25.7	46.2
Age 70–79	30.5	55.0	na[b]
Age 80+	74.7	na[b]	na[b]
Percentage with limitation at baseline who die (n = 2,106)			
Age 50–59	na[c]	0.0	29.1
Age 60–69	0.0	10.5	49.4
Age 70–79	4.6	59.2	80.3
Age 80+	63.6	92.5	15.8
Unweighted number of observations at baseline			
Age 50 to 59	434	515	395
Age 60 to 69	336	766	453
Age 70 to 79	334	966	218
Age 80+	86	331	19
Total	1,190	2,578	1,085

Notes. [a]278 baseline respondents who are lost to follow-up in all subsequent waves but not dead are omitted.
[b]Not applicable since everyone in this age bracket and trajectory group has a limitation at baseline.
[c]Not applicable since everyone in this age bracket and trajectory group are without limitation at baseline.

Table 5. Results From Multinomial Logit Risk-Factor Models of Group Membership

	Model 1		Model 2		Model 3	
	Mid vs. late onset	Early vs. late onset	Mid vs. late onset	Early vs. late onset	Mid vs. late onset	Early vs. late onset
Female	2.118*	2.020*	2.086*	2.063*	1.571*	1.862*
Years of education	−0.071*	−0.149*	−0.067*	−0.146*	−0.099*	−0.133*
Mainlander	0.301	−0.131				
Married in 1996	0.016	0.076				
Urban residence in 1996	−0.047	−0.013				
Proportion of responses by proxy	1.638*	3.559*	1.633*	3.538*	1.603*	3.531*
Female × years of education					0.103*	0.022
Constant	−0.164	−0.609*	−0.123	−0.561*	0.031	−0.681*
Bayesian Information Criterion	−12896.58		−12873.00		−12,876.82	

Note. * $p < .05$.

in the late-onset group; females with less education are in the early-onset group. The addition of the interaction shows that the effect of education varies across sexes. The positive female by years-of-education interaction effect for the mid-onset versus the late-onset groups suggests that education is somewhat less important in determining group membership

for females than it is for males. A significant Wald test (not shown) indicates that the same is true for the early-onset versus mid-onset comparison.

Given the small percentages with specific years of education other than zero and six (35.47% and 33.07%, respectively), we did sensitivity analyses using two-group (0 vs. some) and four-group (0, 1–5, 6, 7+) categorizations of education (data not shown). We found that main effects are robust regardless of how education is coded and that the interaction with female is significant for the two-group specification as in the continuous specification. The model with education measured continuously provides the best overall fit of the three.

Questions were answered by proxy in cases in which individuals were unable because of health problems to respond on their own. Therefore, by survey design, individuals with a higher proportion of survey waves answered by proxy are those who are more likely to have functional limitations. As expected, the models indicate that the greater the proportion of responses by proxy the greater the likelihood of being in the early-onset and mid-onset groups in comparison with late group. A Wald test (data not shown) indicates that proportion proxy is also significantly related to a greater likelihood of being in the early-onset versus the mid-onset group.

Discussion

This analysis of physical functional limitation of Taiwanese aged 50 and older from 1996 to 2007 has identified three common trajectories. This trajectory analysis is the first to jointly model functional limitation (as opposed to other measures of late-life limitation) and mortality. By focusing on functional limitation, an outcome that is relatively common by late middle age, it is possible to trace its developmental path from late middle to very old age. With this measure, it is also possible to focus more closely on underlying capacity than is possible in analyses of trajectories of limitations in activities of daily living and instrumental activities of daily living, which are more likely than physical functional limitations to be affected by the circumstances in which activities are carried out. The analysis also assessed the association between multiperiod functioning trajectories and period-to-period onset, recovery, and mortality transitions that underlie them. Finally, the associations of a series of risk factors with trajectory group membership were examined.

We have eight main findings. First, for all groups, functional limitation probabilities increase with age. That is, none of the trajectory groups could be described as showing a decreasing or even a stable probability of having a functional limitation with increasing age. Second and related, there is virtually no escape from functional limitation given survival to very old age of the typical member of each group, as indicated by the model estimates.

Third, one critical difference among the groups is the age at which functional limitations become likely. About half of Taiwanese aged 50 and older are members of the mid-onset group. About a quarter each are members of the late-onset and early-onset groups. The age at which having a functional limitation becomes more likely than not is 81 for the late-onset group, 69 for the mid-onset group, and 55 for the early-onset group.

Fourth, once the probability of functional limitation begins to increase, rates of increase by age are fairly consistent across groups. It takes 22 years for the mid-onset group and 19 years for both the early-onset and late-onset groups to progress from a probability of limitation of 0.25 to 0.95, and 14 years to increase from a probability of limitation from 0.50 to 0.95 for all three groups. Most members of the early-onset group will likely have functional limitation (0.95 probability) if they live to just 69 years of age, as opposed to ages 83 and 95 for those in the mid-onset and late-onset groups, respectively. Obviously, because some will not survive, not everyone will experience functional limitations between age 50 and death.

Fifth, relative differentials in mortality by group map to relative differentials in functional limitation only between ages 70 and 83 years. Before age 70, chances of dying are very small for both the late-onset and mid-onset groups and somewhat higher for the early-onset group. Interpreting mortality patterns after age 83 is difficult, given that numbers become small as individuals die out, particularly in the early-onset group. Results indicated a crossover with mortality becoming higher for the mid-onset versus the early-onset group, but this finding should be tested in the future with larger samples to determine whether it is genuine or a function of sampling error. If it is real, there are several possible explanations: It could be that survivors from the early-onset group represent a more select, robust subset of individuals. They may be people who experienced early-life disease or injury, but who as a result of improved management of their conditions are surviving into old age, albeit with some functional limitation. Another possibility is that the crossover indicates some degree of independence between physical functional limitation and mortality. More severe types of limitation not considered in the current study, such as limitations in activities of daily living, appear to be more closely linked to mortality (Zimmer et al., 2012). But some potentially fatal health problems, such as myocardial infarction, may occur with little previous physical functional limitation. Malignant neoplasm, which is a dominant cause of death for those aged 45 and older, is not often associated with functional limitation, which is in contrast to non-fatal conditions that are associated with functional limiations, such as arthritis (Martin et al., 2010). Finally, females are more likely to be members of the early-onset group than are males, and females are also more likely than males to survive. Specifically, 32% of females are members of the early-onset group compared with 18% of males, but only 30% of females in the group die before the fourth data wave is completed versus 65% of males in the group.

The sixth finding is that despite the complex pattern of mortality trajectories relative to trajectories of functional limitations, summary measures of mortality probabilities by group do follow the hierarchy of the functional limitation trajectories with the early-onset group experiencing the earliest death on average. But their relatively early mortality does not mean that they experience only short periods of limitation. The number of years spent on average between the age when functional limitation becomes likely and death becomes likely (both probabilities ≥ 0.50) are just over 14 years for the late-onset group, 17 years for the mid-onset group, and 25 years for the early-onset group. So on average, individuals in the early-onset group, representing 27% of the population at baseline, are more likely than not to spend a long period before death with at least one physical functional limitation.

The seventh finding is that there is a close association between the multiperiod trajectories and the underlying shorter term transitions. For instance, those in the late-onset group generally do not have functional limitations when first observed. However, if first observed after age 70, they are more likely than not to experience an onset. Unlike those in other groups, the few in the late-onset group who are first observed with a limitation always experience recovery. Members of the early-onset group, in contrast, always have a limitation at first observation or experience an onset regardless of age at baseline. Those who have a limitation and are 60 or older at baseline rarely recover. In sum, the transition analysis has shown that each trajectory group is characterized by quite specific transition experiences.

The baseline limitation of the two younger age brackets in the mid-onset group is relatively low, much closer to that of the late-onset group than the early-onset group. Similarly, the rates of recovery for those first observed before age 70 with a limitation are essentially 100% for the two groups. But at higher ages, the patterns for the mid-onset group are closer to those of the early-onset group. As a result, it may be beneficial to focus intervention on the mid-onset group to further prevent onset (e.g., through better management of underlying chronic conditions) or enhance recovery (e.g., through physical therapy) at older ages. This group is the largest, constituting half of the population, and targeted interventions for them potentially could have the greatest effect on total population prevalence of limitation.

The eighth and final finding is that education plays less of a role for females than males in predicting trajectory group membership. Earlier research has shown education to be associated with onset of physical functional and other limitation in Taiwan (Zimmer et al., 1998). Our finding that education is less important for females than males in predicting trajectory group membership is new. Analyses of our sample indicates that on average, males had over twice as many years of education compared with females (6.45 vs. 3.06 years), and 53% of females had no education at all as opposed to 20% of males. If education associates with functional limitation trajectory, it could be because, in so far as education is an indicator of social status, and social status in turn impacts on functional limitation outcomes, in Taiwan, as in other more patriarchal societies, social status for a male/female married couple is tied traditionally to the husbands' characteristics. This is because husbands typically are, first, the main breadwinners; second, household heads (assuming no older male in the household); and third, as noted above, likely to have the higher level of education of the two. In analysis conducted in Mainland China (Zimmer et al., 2012), education was found not to be associated with ADL disability trajectory group membership for females aged 80 and older, 84% of whom had no education at all. But a small group of educated males aged 80 and older tended to have moderate but stable limitations, suggesting that perhaps the relative availability of resources for this advantaged group allowed its members to survive to old age with moderate disability. Whether this sex differential in association of education with late-life trajectories of functional and activity limitations holds in other societies no doubt depends on cultural practices, as well as level of female education, and as education increases over time, the differential may change. The results reported here may well be a function of the choice of outcome measure and should not be presumed to hold for other types of limitations, such as those of daily activities, which reflect a gap between underlying capacity of the individual and the demands of the tasks in the environment in which they are being carried out. Moreover, we have focused on a summary measure indicating difficulty with any one of seven functional limitations. There may be individual functions that are primarily responsible for the patterns that we find and could be the focus of further research. In addition, our results may be a function of the length of intervals between survey waves. Within the 3-year and 4-year windows of our data, there are likely numerous transitions that are not reflected in the data collected in the four waves. An individual who is categorized as having remained stable over time may have indeed experienced one or more changes in functional limitation status during the time period.

Population aging and survival to older and older ages are positive markers of socioeconomic progress and epidemiological change in rapidly developing societies. But our study suggests that functional limitations are unavoidable for most with increasing age. Given the growth of the older population, the result will be a growth in numbers of people with functional limitation unless onset can be delayed considerably. Given the large size of the mid-onset group and the patterns of onset by age at baseline, our results suggest that it might be most beneficial to intervene in this group early on to delay additional onset and enhance recovery at older ages. Although there are many possible interventions to reduce progression from functional limitations to limitations in activities (e.g., environmental modifications, use of assistive technology, and change in how activities are carried out), it may well be more cost effective to intervene earlier in the disablement process through prevention of and rehabilitation

from physical functional limitations in order to maximize the proportion of the older population that is able to live independently and participate fully in activities of life.

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