Socioeconomic Stratification and Multidimensional Health Trajectories: Evidence of Convergence in Later Old Age

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Abstract

Objectives. This research sought to examine socioeconomic stratification in the joint trajectories of physical, emotional, and cognitive functioning among older Americans and how it differs by age groups.

Methods. We used data from a nationally representative sample of 9,237 Americans age 65 or older from the Health and Retirement Study, who were observed biennially from 1998 to 2010. Joint trajectories of physical, emotional, and cognitive functioning were characterized using a group-based mixture model. We then applied multinomial logistic regression analysis to evaluate their linkages with socioeconomic status and how the linkages differ by age groups.

Results. We identified four distinct patterns of joint changes in physical, emotional, and cognitive functioning over time. Accounting for 29.3%, 23.5%, 24.5%, and 22.6% of the older Americans, respectively, these trajectory patterns characterized groups of individuals experiencing minimal to severe levels of impairment and deterioration. Lower education, income, and net worth were associated with trajectories featuring greater impairment or more rapid deterioration in these functional dimensions. Disparities based on education, however, attenuated in later old age, whereas health benefits associated with higher income and higher net worth persisted into advanced age.

Discussion. Distinct patterns of joint trajectories of physical, emotional, and cognitive functioning exist in old age. There were significant socioeconomic differences in the joint trajectories, with education-based inequality in health converging in later old age. Further research identifying strategies to alleviate the disproportionate burden of poor multidimensional health trajectories in lower socioeconomic groups is important.

Key Words: Socioeconomic status—Joint trajectories—Elderly—Disability—Depression—Cognition.

ALTHOUGH health advantage among individuals with higher socioeconomic status (SES) such as education and income is well-established (House, Lantz, & Herd, 2005; Mirowsky, Ross, & Reynolds, 2000; Ross & Wu, 1996), how the socioeconomic stratification of health interacts with age is not well understood. The cumulative advantage theory proposes that the health benefit of higher SES accumulates throughout the life course resulting in greater socioeconomic disparity in health in older ages compared to younger ages (Dannefer, 2003; Ross & Wu, 1996). In contrast, the theory of social stratification of aging and health and the age-as-leveler hypothesis argue that the SES gap in health peaks in early old age, after which it diminishes because of increasing social welfare support such as Medicare or Social Security, “universal” frailty in old age, and early mortality of individuals in the lower SES group (House et al., 2005; Willson, Shuey, & Elder, 2007).

The empirical evidence on age differences in socioeconomic disparity in health is mixed. Some studies demonstrate increasing socioeconomic inequality in health without late life convergence (Aneshensel, Frerichs, & Huba, 1984; Prus, 2007; Ross & Wu, 1996), whereas others support late life convergence (Beckett, 2000; Herd, 2006; House et al., 2005). The inconsistent findings call for more research on how socioeconomic inequalities in health change with age (Ross & Mirowsky, 2010), which can expand our knowledge of health disparities over the life span.

A focus on age differences in the linkage between SES and health also fits well with a long tradition in gerontology which emphasizes the distinction between age groups, particularly the young–old and old–old (Neugarten, 1974). For instance, the perspective of age stratification suggests that the hierarchical ranking of people by age groups is a major source of inequality in access to society’s rewards, power, and privileges (Riley, 1971; Riley, 1987). These are closely associated with aging subculture and age norms, which may have major consequences for physical and mental health and may interact with how SES influences health.

In addition, SES is a broad term referring to a person’s general position in the social system and has
multiple components, such as education, income, and net worth (Pampel, Krueger, & Denney, 2010). These are not interchangeable components because they influence health through different mechanisms. For example, education may influence health by enhancing a person’s financial status, which provides more resources for maintaining good health (commodity theory), and by increasing a person’s knowledge, ability, and skills to achieve better health (e.g., engaging in healthy lifestyles) (concept of human capital), suggesting that education influences health beyond its financial implications (Mirowsky & Ross, 2003; Ross & Mirowsky, 2010). Because of these complex relationships between the various SES components and health, a close examination of how different SES components interact with age in influencing health would allow for more targeted social and policy strategies for alleviating health disparities in old age (House et al., 2005).

Empirical research documenting the linkages between SES and health has evolved from cross-sectional studies or short-term longitudinal studies in the 1990s (e.g., Ross & Wu, 1996) to multilevel models based on longitudinal data spanning an extended period of time (e.g., Karlamangla et al., 2009; Liang et al., 2008; Xu, Liang, Bennett, Quinones, & Wen, 2010; Yang, 2007), which provide a more dynamic view of the relation between SES and health. Nonetheless, most studies have analyzed one outcome measure at a time providing little information on how the trajectories across health domains intertwined dynamically.

The process of aging is characterized by many biological and psychological changes (Glisky, 2007). Both the frailty concept and comprehensive geriatric assessment emphasize the multidimensional nature of health. Frailty measures a state of increased vulnerability for adverse outcomes (e.g., deaths, institutionalization) resulting from cumulative declines in multiple physiological systems, and emphasizes multidimensional evaluation and management (Fried, Ferrucci, Darer, Williamson, & Anderson, 2004; Fried et al., 2001; Kulminska et al., 2008; Malaguarnera, Vacante, Frazzetto, & Motta, 2013; Rockwood & Mitnitski, 2007; Rodriguez-Manas et al., 2013). Recent development of multidimensional indices, such as the multidimensional prognostic index (Pilotto et al., 2008), multivariate index of healthy aging (Swindell et al., 2010), and universal outcome measures (Working Group on Health Outcomes for Older Persons with Multiple Chronic Conditions, 2012), also recognizes multisystem changes in older adults and strives to capture aggregate information across multiple physiological and functional domains. Hence, it is important to model the changes in multiple health domains in order to understand how the trajectories of one domain are linked to those of the other domains, as well as to identify distinct configurations of joint trajectories across multiple domains. Neither of these can be achieved by modeling the trajectory of a single health outcome at a time. Findings from the multidimensional health trajectories can help elucidate the health care burden and needs of older Americans and enable tailored care for persons exhibiting different patterns.

Moreover, the multiple components of SES may influence different aspects of health. For example, research has shown that intellectual abilities and mental simulation stemming from education may enhance cognitive development (Bosma, van Boxtel, Ponds, Houx, & Jolles, 2003; Ross & Mirowsky, 2010), such that education may be associated with cognitive declining more than other SES indicators. Therefore, examining how different SES components are linked to multidimensional health trajectories would provide a more comprehensive view of health disparities in old age.

Another improvement in empirical aging research has been the identification of population heterogeneity in health trajectories, rather than the average tendencies in health decline (Dodge, Shen, & Ganguli, 2008; Gill, Allore, Gahbauer, & Murphy, 2010; Liang, Xu, Quinones, Bennett, & Ye, 2011). These studies greatly enrich the literature on successful aging which recognizes substantial variability in physiological and functional changes in aging, by distinguishing between older people with minimal or no physiological loss (i.e., aging successfully) and those with non-pathological age-related losses (i.e., usual or normal aging) or pathological aging that occurs as a result of disease (Kane, Ouslander, & Abrass, 1999; Rowe & Kahn, 1987; Schaie, 1996). Similar concepts of healthy aging, robust aging, and positive aging have been introduced by other researchers (Bowling, 1993; Garfein & Herzog, 1995; Swindell et al., 2010). The frailty concept also distinguishes robust, prefrail and frail phenotypes, reflecting individuals with no, intermediate, and severe presence of frailty characteristics, respectively (Fried et al., 2001), and differentiates between well and frail elders (Rockwood, Fox, Stolee, Robertson, & Beattie, 1994). By identifying older adults with exceptional performance across a broad range of domains, this framework can help discern factors that explain success and inform the development of preventive strategies.

Recently, investigators began to examine population heterogeneity in multidimensional health trajectories (Chang, Lu, Lan, & Wu, 2013; Hsu & Jones, 2012; Wickrama, Mancini, Kwag, & Kwon, 2013). However, these studies either did not focus on socioeconomic disparities or only examined socioeconomic inequalities in health trajectories within a specific age group. Age differences in the linkages between SES and multidimensional health trajectories remain unexplored, thus calling for an evaluation over a wider age range in order to characterize any converging or diverging pattern across different age groups. In this research, we addressed this question by examining how the linkages between SES and multidimensional health trajectories vary with advancing age, where multidimensional health dynamics was assessed across physical, emotional and cognitive functioning domains.

**Hypotheses**

Informed by the theoretical and empirical work summarized above, we propose the following hypotheses.
Hypothesis 1.—There are at least three distinct patterns of joint changes in physical, emotional, and cognitive functioning over time, generally corresponding to successful, usual and pathological aging. In particular, we hypothesize that there are individuals with minimal impairment in all three health dimensions throughout an extended period of time, while in contrast, some persons may experience severe difficulty or substantial deterioration across all three dimensions over time. People with trajectory patterns in between these two scenarios are considered as exhibiting intermediate decline in physical, emotional, and cognitive functioning.

Hypothesis 2.—There is substantial socioeconomic disparity in the likelihood of experiencing different joint trajectories of physical, emotional, and cognitive functioning, such that individuals with less education attainment, lower income, or lower net worth at baseline are more likely to experience joint trajectories characteristic of greater functional impairment or deterioration (Hypothesis 2a). However, such socioeconomic differences attenuate in later old age (Hypothesis 2b).

METHODS

Data Source and Study Sample

We used data from the ongoing, biennial Health and Retirement Study (HRS) (Health and Retirement Study, 1998–2010). HRS started in 1992 with a nationally representative survey of Americans born in 1931–1941 and their spouses, regardless of age, if married. Additional birth cohorts were added in subsequent years. Beginning in 1998, the HRS provides a nationally representative sample of non-institutionalized Americans age 51 and older. Consequently, we used 1998 as the baseline for our analysis to characterize the relative distribution of the joint trajectory patterns in a nationally representative sample. We limited our analysis to respondents aged 65 and older at baseline because the HRS survey did not routinely collect several indicators of cognitive functioning from younger respondents.

After excluding proxy responses (for whom assessment of depressive symptoms was not available) and respondents who were not age-eligible in 1998 or had unknown race/ethnicity or a race/ethnicity other than white, black or Hispanic, our final analytic sample included 9,237 respondents who were 65 years of age or older in 1998, with up to 7 repeated observations spanning 12 years (1998–2010). The 9,237 respondents contributed a total of 41,674 observations with an average of 4.5 repeated observations per respondent. To generate results representative of the U.S. older adult population, HRS sample weights from the baseline year (i.e., 1998) were applied to all analyses. Additional information about HRS is available at its website (http://hrsonline.isr.umich.edu).

Outcome Measures

Physical functioning was measured based on respondents’ reported limitations in performing six activities of daily living (ADLs) (walking across a room, dressing, bathing, eating, getting in or out of bed, and using the toilet) and five instrumental activities of daily living (IADLs) (using telephone, managing money, taking medications, shopping for grocery, and preparing hot meal). Each item was coded as 0 for having no difficulty at all, and 1 for having at least some difficulty. The summary score ranged from 0 to 11 with a higher value indicating greater impairment. Combined ADL and IADL items have been shown to have enhanced range and sensitivity for measuring functional status (Spector & Fleishman, 1998). While there is a lack of consensus on how to define disability using the combined ADL/IADL index, having two or more ADL limitations has been commonly used to define severe disability in research and in public and private long-term care programs (Stallard, 2011; Wu, Huang, Wu, McCrone, & Lai, 2007).

Emotional functioning was assessed by an abbreviated Center for Epidemiologic Studies Depression (CES-D) scale with eight dichotomous items reflecting a respondent’s feelings much of the time over the week prior to the interview (feeling depressed, feeling everything was an effort, sleep was restless, feeling lonely, feeling sad, feeling happy, enjoying life, could not get going, and having a lot of energy). These items were from the original CES-D scale with demonstrated internal consistency and factor structure comparable to that of prior versions of the CES-D (Turvey, Wallace, & Herzog, 1999). We reverse-coded the positive items to construct a summary score (range 0–8), with higher scores indicating more pronounced depressive symptoms. Prior research has demonstrated the validity of using a score of 4 on this abbreviated CES-D scale as the cutoff for defining clinically relevant depressive symptoms (Steffick, 2000).

Cognitive functioning was measured by a composite score based on tests of immediate word recall, delayed word recall, serial 7’s test, backwards count, and naming tests (date naming, object naming, president/vice president naming) (Ofstedal, Fisher, & Herzog, 2005). These tests assessed short- and long-term memory, orientation to surroundings, knowledge of current events, language and ability to perform mathematical tasks. Test results were reverse-coded to form a summary score (range 0–35), with higher values indicating greater cognitive impairment. These tests have shown desirable psychometric properties with strong internal and construct validity (Herzog & Wallace, 1997). A score of 25 or higher has been suggested as defining cognitive impairment based on previous work using HRS data (Langa et al., 2008).

Explanatory Variables

We measured each respondent’s SES using education, income, and net worth. We measured education by years of schooling (capped at 17 years of education), and income by equivalence scale adjusted household income (Nicholas & Wiseman, 2009; Short, 2013). In addition, because income...
alone may not fully capture a person’s economic status in old age, we included household net worth (i.e., value of total wealth minus total debt) as an additional SES indicator (Robert & House, 1996). Both income and net worth were measured at baseline using quartile indicators. Because our data suggested a similar effect of higher income and higher net worth quartiles which is consistent with prior research (Robert & House, 1996), we combined the two higher quartiles as the reference group.

Similar to other studies (House et al., 2005), we conceptualized SES as a function of gender and race/ethnicity, and included them as control variables. Gender was constructed as a binary indicator (1 if female, and 0 if male) and race/ethnicity was indicated as non-Hispanic black, Hispanic, or non-Hispanic white (reference group). In addition, because different birth cohorts entered HRS at different ages, we controlled for each person’s baseline age, measured as a continuous variable in years. Our model also controlled for baseline differences in health condition across individuals, assessed by respondent self-rated overall health (1 = excellent, 2 = very good, 3 = good, 4 = fair, and 5 = poor) and number of chronic diseases (including heart disease, cancer, stroke, diabetes, hypertension, lung disease, and arthritis).

Data Analysis
To identify major patterns of joint changes in physical, emotional, and cognitive functioning, we used the group-based, joint trajectory modeling approach developed by Nagin and colleagues via a SAS macro PROC TRAJ (Jones & Nagin, 2007; Nagin, 2005). Each joint trajectory group consisted of three trajectories—one for physical functioning, a second for depressive symptoms, and a third for cognitive impairment.

Based on the empirical distributions of the outcome measures, we used a zero-inflated Poisson (ZIP) model for ADL/IADL limitations and CES-D depressive symptoms, and a censored normal model for cognitive functioning (minimum = 0, maximum = 35). After comparing the goodness-of-fit in alternative models, we used a linear function for the Poisson part of the ZIP model (i.e., the logarithms of ADL/IADL limitations and CES-D were specified as linear functions of time), while the trajectory of cognitive impairment was best modeled as a quadratic function of time. Time was measured as the number of years since the baseline (i.e., 1998). We assessed models with 2–10 joint trajectory groups and determined the optimal number of groups based on several criteria: the Bayesian Information Criteria (BIC) index, average posterior probability of group membership, size of the smallest group, and an evaluation of whether additional groups identified in successive models represent substantially distinct groups or a mere subdivision of major groups already identified.

Once the joint trajectory groups were identified using PROC TRAJ, we assigned each respondent to a joint trajectory group based on the maximum estimated posterior probability of his/her group membership. We then conducted a separate multinomial logistic regression analysis to examine how SES affects a person’s likelihood of having different trajectory patterns, where group membership was the dependent variable and person-level characteristics were the explanatory variables. While doing so, we incorporated each person’s posterior probability of group membership as additional weights in analysis to account for uncertainty in group assignment. These weights were further normalized in order to appropriately account for the sample size.

To assess how SES disparities in multidimensional health trajectories differ by age, we estimated an additional multinomial logistic regression model with interaction terms between SES indicators and different age categories, including 65–69 years (reference category), 70–74 years, 75–79 years, 80–84 years, and 85 years or older. To accommodate these age categories, the main effect of baseline age was assessed as an ordered variable in this model (0 = 65–69 years of age, 1 = 70–74 years of age, 2 = 75–79 years of age, 3 = 80–84 years of age, and 4 = 85+ years of age).

We included in the multinomial logistic regression indicators of mortality (1 if the respondent died during the follow-up period, and 0 otherwise) and attrition (1 if the respondent missed at least one interview during the follow-up period for reasons other than death, and 0 otherwise) to control for their potential confounding effect on socioeconomic health disparities. These indicators were treated as confounding variables and were not meant to be causal variables or interpreted as such (Hedeker & Gibbons, 2006). This was similar to the approaches used by other investigators in dealing with selection bias (Mroczek & Spiro, 2005).

To minimize the loss of data due to item missing, multiple imputation was undertaken with three imputed datasets using the NORM software (Rubin, 1987; Schafer, 1997). Parameter estimates and their standard errors were derived by averaging across the three imputations and by adjusting for their variance. We considered estimates with p-values less than 0.05 as statistically significant. We conducted all analyses using SAS version 9.3 (SAS Institute Inc., Cary, NC).

Results
Sample Characteristics
Representative of the non-institutionalized, older adult Americans population (age 65 and older) in 1998, individuals in our sample had a mean age of 74.7 (standard deviation (SD) = 6.6) at baseline (Table 1). Fifty seven percent were young-old (i.e., 65–74 years of age). Most were female (59.7%) and non-Hispanic white (87.4%). Thirty-two percent were less than high school education, while 34.3% had more than high school education. The average annual income (after adjustment for equivalence scale) was $28,961 (SD = $40,804). On average, the respondents reported 1.8 chronic diseases at baseline, with
arthritic, hypertension, and heart disease being the most common conditions. During the 12-year follow-up period, 47.0% died and an additional 16.1% missed one or more interviews.

**Joint Trajectories of Physical, Emotional, and Cognitive Functioning**

When comparing models with 2–10 trajectory groups, the improvement in BIC score leveled off after four groups. Subsequent models with more than four groups only subdivided the major groups already identified. A four group model also achieved optimal average posterior probability of group membership with values ranging from 0.82 to 0.92 across the four trajectory groups (a probability of 0.9 or higher was considered excellent fit and a value below 0.7 was considered poor fit) (Nagin, 2005). Therefore, we chose a four group model in our final analysis.

We labeled the four distinct trajectory groups as: minimal impairment, moderate impairment with increasing cognitive deficit, moderate impairment with increasing physical and emotional deficit, and significant and increasing impairment (Figure 1). They accounted for 29.3%, 23.5%, 24.5% and 22.6% of the sample, respectively. Individuals in the minimal impairment group had almost no ADL/IADL limitations and depressive symptoms throughout the 12 years of observation and little cognitive difficulty over time. In contrast, those in the significant and increasing impairment group exhibited a high level of impairment in all three domains, with more than two ADL/IADL limitations and three depressive symptoms most of the time and a cognitive impairment score close to 25 at the end of the observation period. The scores also steadily worsened over the study period. The rest of the respondents fell into the two middle groups, one exhibiting moderate impairment with increasing physical and emotional deficit, while the other showing moderate impairment with increasing cognitive deficit. Both groups, however, had functioning scores within the normal range in all three domains.

The small but significantly positive linear terms in the ZIP models for physical and emotional functioning suggest that the logarithms of the ADL/IADL limitations and CES-D score increased linearly over time (Table 2). Trajectories of cognitive impairment, however, had positive linear and quadratic slopes indicating that cognitive impairment increased over time at an accelerated rate.

These results lend support to our Hypothesis 1, i.e., presence of significant heterogeneity in the joint trajectories of physical, emotional, and cognitive function among older Americans.

**Socioeconomic Disparities in Multidimensional Health Trajectories**

In multinomial logistic regression analysis with adjustment for gender, race/ethnicity, and baseline age and health status, higher baseline SES showed a clear protective effect. Education, income, and net worth were each statistically significant when used individually to evaluate the relationship with trajectory group membership (Models 1–3 in Table 3). When included together in a single model, they all remained statistically significant, indicating that they each were independently associated with multidimensional health trajectories. People with more education were less likely to have moderate impairment with increasing cognitive deficit, moderate impairment with increasing physical and emotional deficit, or significant and increasing impairment trajectories (as opposed to minimal impairment), while those with lower income or net worth were at a higher risk for experiencing such trajectories (Model 4 in Table 3). These results support our hypothesis that people with lower SES were more likely to experience joint trajectory patterns featuring greater functioning impairment/deterioration (Hypothesis 2a).

Examination of interaction terms between SES and age categories showed no significant age difference in the association of income or net worth with multidimensional health trajectories (data not shown). However, there is a significant interaction effect between education and baseline age on the likelihood of experiencing different health trajectories, particularly trajectories characteristic of greater cognitive deficit (Table 4). In relation to the likelihood of experiencing significant and increasing impairment (relative to minimal impairment), the interaction terms between education and age 80–84 and age 85+ (compared to age 65–69) were statistically significant and positive. Likewise, there was a significant and positive interaction effect between education and age 85+ (compared to age 65–69) on the likelihood of experiencing moderate impairment with increasing cognitive deficit (relative to minimal impairment). In conjunction with the significant and negative main effect of education, these interaction effects indicate that for individuals age 80 or older at baseline, the protective effect of education...
was attenuated. This is consistent with our hypothesis that health advantage among individuals with higher education diminishes at more advanced age, i.e., a convergence of education-based health gap (Hypothesis 2b). This age and education interaction effect, however, was not significant for the likelihood of experiencing moderate impairment with increasing physical and emotional deficit (relative to the minimal impairment trajectory).

### Association of Other Person-Level Characteristics with Joint Trajectory Patterns

More advanced age and being in a racial/ethnic minority group were associated with an increased likelihood of experiencing moderate impairment with increasing cognitive deficit, moderate impairment with increasing physical and emotional deficit, or significant and increasing impairment trajectories, as opposed to

<table>
<thead>
<tr>
<th>Growth parameter</th>
<th>Minimal impairment</th>
<th>Moderate impairment with increasing cognitive deficit</th>
<th>Moderate impairment with increasing physical and emotional deficit</th>
<th>Significant and increasing impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical functioning (ADL/IADL limitations), zero-inflated Poisson model</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Intercept</td>
<td>−3.111***</td>
<td>−1.652***</td>
<td>0.377***</td>
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<td>0.181***</td>
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<td>Emotional functioning (CES-D), zero-inflated Poisson model</td>
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<tr>
<td>Intercept</td>
<td>−0.510***</td>
<td>0.041</td>
<td>1.050***</td>
<td>1.189***</td>
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<tr>
<td>Linear term</td>
<td>0.010</td>
<td>0.030***</td>
<td>0.014***</td>
<td>0.014***</td>
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<tr>
<td>Cognitive functioning (composite cognitive impairment score), censored normal model</td>
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<tr>
<td>Intercept</td>
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<td>11.005***</td>
<td>18.870***</td>
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<tr>
<td>Linear term</td>
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<td>0.199***</td>
<td>0.212***</td>
<td>0.527***</td>
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<td>Quadratic term</td>
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<td>0.021***</td>
<td>0.009***</td>
<td>−0.003</td>
</tr>
<tr>
<td>Group proportion</td>
<td>29.3%</td>
<td>23.5%</td>
<td>24.5%</td>
<td>22.6%</td>
</tr>
</tbody>
</table>

Model fit statistics

Bayesian information criterion: −232,764.4

*Notes. N = 9,237 individuals. Data reflect aggregate results from multiple imputation. ADL = activities of daily living; CES-D = Center for Epidemiologic Studies Depression scale; IADL = instrumental activities of daily living. *p < .05, **p < .01, and ***p < .001.*
minimal impairment (Model 4 in Table 3). Women were more likely to follow a trajectory pattern characteristic of moderate impairment with increasing physical and emotional deficit, or significant and increasing impairment, but less likely to have moderate impairment with increasing cognitive deficit (Model 4 in Table 3). In addition, individuals who died or were lost to follow-up had a greater risk of experiencing poor functioning trajectories, especially significant and increasing impairment (Model 4 in Table 3).

### Discussion

Using nationally representative data, we characterized population heterogeneity in functioning status among older Americans from both a multidimensional and a dynamic perspective. We identified four distinct patterns of joint changes in physical, emotional, and cognitive functioning over time and significant SES differences in trajectory group membership. More importantly, we demonstrated that education-based differences in health converge in later old age, supporting the theory of social stratification of
aging and health and the age-as-leveler hypothesis (House et al., 2005; House et al., 1994).

Although the typology of successful aging, usual aging, and pathological aging does not map fully into the four groups of joint trajectories we observed, a meaningful correspondence does appear to exist between the typology and our empirical observations. Indeed, one may regard the minimal impairment group to parallel successful aging, while the significant and increasing impairment group to mimic pathological aging. At the same time, moderate impairment with increasing cognitive deficit and moderate impairment with increasing physical and emotional deficit, together accounting for 48% of the older Americans, can be viewed as two subtypes of usual aging. These results suggest that there may be more than one type of usual aging.

The linkages between socioeconomic stratification and multidimensional health trajectories are consistent with results from a recent study by Wickrama et al. (2013) showing distinct groups of individuals experiencing maintaining, deteriorating, and persistently high health problems in late old years and a strong association of these groups with social stratification. We, however, extended their research by including individuals age 65–74, as well as those older than 85 years, to assemble a large, nationally representative sample of Americans age 65 and older. This addresses an important limitation in prior research that often excluded the oldest-old when studying successful aging (Garfein & Herzog, 1995), or restricting to people at more advanced ages for characterizations of frailty (Swindell et al., 2010).

By doing so, we were also able to test how socioeconomic disparities in health differ by age groups and provide evidence for converging disparities in health associated with education in later old age. This finding is consistent with prior research showing that education exerts greater impact on the onset of health problems or functional deficits, whereas income has stronger effect on their progression (House et al., 2005; House et al., 1994). At more advanced age, most people would have already suffered some health problems or functional deficits, limiting the benefit of education advantage. In contrast, income and net worth provide important economic resources to help cope with existing health conditions and therefore they continue to affect health trajectories in later life. These results suggest that education, income, and net worth interact with age differently in their association with multidimensional health trajectories. Although the protective effect of education attenuates in later old age, social policies and programs to reduce inequalities in financial resources may continue to help mitigate health disparities.

Consistent with prior literature suggesting that more years of education may enhance cognitive development (Bosma et al., 2003; Ross & Mirowsky, 2010), we found that education had a stronger association with the trajectory of moderate impairment with increasing cognitive deficit than the trajectory of moderate impairment with increasing physical and emotional deficit (where there is minimal cognitive decline). This contrast is less evident for other SES indicators. It has been posited that intellectual abilities and mental simulation stemming from education may have a protective effect on a person’s cognitive functioning (Bosma et al., 2003). In addition, different education attainment may expose people to different levels of mental stimuli at work, which can also contribute to the education-based differences in cognitive decline (Bosma et al., 2003).

The observed heterogeneity underlying the average decline in functioning ability among older Americans underscores the importance of a personalized, rather than a one-size-fits-all approach to the management of geriatric patients. For instance, for seniors experiencing minimal functional limitations, care should emphasize prevention, while effective treatment and coping strategies should be the focus for those with severe impairment. The trajectories
across the three functional dimensions also demonstrate substantial synchrony, such that impairment or deterioration in one dimension is often accompanied by impairment and deterioration in the others. While the specific mechanisms of the co-occurring functioning impairment are yet to be fully defined, our findings highlight the need for a more comprehensive approach in geriatric care. Single-prong interventions may result in hampered effectiveness (Wilkins, Kiosses, & Ravdin, 2010). In addition, integrating medical care with non-medical interventions (e.g., psychosocial interventions, behavior interventions, and occupational therapy) and providing interdisciplinary team care (e.g., involving geriatricians, social workers, mental health professionals, and occupational therapists) may be particularly beneficial (Reilly, Challis, Burns, & Hughes, 2003; Wright, Hazelett, Jarjoura, & Allen, 2007).

Several limitations of our study should be noted. First, our assessment of physical function was based on self-reported limitations in ADL/IADL activities. Although these are well-accepted instruments, more objective performance-based measures (e.g., grip strength test, gait speed) would provide additional insights. Second, several studies have recommended the incorporation of social health indicators in the assessment of successful aging, even though there is still debate regarding whether social functioning should be conceptualized as a component or a predictor of successful aging (Bowling, 2007; Garfein & Herzog, 1995). Due to the limited longitudinal data on social functioning measures in HRS, we were not able to model the trajectory of social functioning in the current analysis. Future research including social functioning as an additional domain would expand our understanding of the multidimensional health trajectories in aging. Third, our study focused on age differences in the linkages between SES and joint health trajectories. SES may also interact with other important ascribed social characteristics, such as gender and race. Further research is needed to examine the interaction between these ascribed characteristics and SES in influencing older adults’ multidimensional health trajectories. Fourth, mortality and attrition are important issues to consider when analyzing longitudinal health data, particularly in older populations. Our identification of joint trajectories assumed that data were missing at random, and included information on individuals who died or dropped out until the time of their death or loss to follow-up. In addition, we incorporated indicators of mortality and attrition in the multinomial logistic regression to control for their potential confounding effect on our estimation of socioeconomic health disparities. However, we recognize that to the extent there was informative missingness or selective survival, our depiction of the joint trajectories might underestimate the level of impairment or rate of deterioration, especially at older ages. Fifth, because individuals from different birth cohorts were observed at different ages, we were not able to isolate age effect from cohort effect. Findings from this study should be interpreted as age differences rather than age effects. Finally, when studying health trajectories over an extended period of observation (as in this current study), many of the covariates could change over time (e.g., number of chronic diseases). To ensure a clear time sequence between these covariates and changes in the outcome variables, our models used baseline measures of these covariates. Future research accounting for the role of time-varying covariates will enhance our understanding of their effect on the course of functional change in old age.

In conclusion, we identified four distinct groups of older Americans experiencing different patterns of concomitant changes in physical, emotional and cognitive functioning over time, with significant socioeconomic disparities in group membership. Disparities based on education, however, attenuate in later old age, particularly with respect to its benefit in reducing the likelihood of experiencing health trajectories characteristic of greater cognitive deficit. In contrast, health benefit associated with higher income and net worth persists into advanced age. Further research identifying strategies to alleviate the disproportionate burden of poor multidimensional health trajectories in lower SES groups is important.

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References


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