Disparities in Disability Life Expectancy in US Birth Cohorts: The Influence of Sex and Race[*]

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Abstract

Disparities in chronic diseases, disability, and mortality by sex and race are a source of inequality among the elderly in the United States. Differential changes in disability life expectancy and total life expectancy over time are a public health concern affecting future demand for medical care and services. They are also a public policy concern affecting the fiscal viability of the Social Security and Medicare programs. I address the previously unanswered question of whether some race-sex groups of actual birth cohorts live longer healthy lives as well as longer lives when compared with others. In particular, I study disparities in the expected remaining life in mild and severe disability by race and sex in US cohorts born between 1904 and 1909. To estimate the quantities, I employ a refined definition of physical disability and apply a new extension of Sullivan's method to actual birth cohorts. The results suggest that black women are the most disadvantaged group and spend the least proportion of their expected remaining life free of either mild or severe disability. The most striking finding is concordant compression of severe disability among all race-sex groups. Decreases in the expected remaining life in severe disability are associated with nearly constant expected total remaining life over time. The results imply that the experience of aging may be worst for black women and the individuals in this group may require greater long-term care needs.

Key Words: Demography, Disability, Gender, Life Tables, Morbidity, Mortality, Race, Sullivan's Method.

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1 Introduction

Racial and sex disparities in chronic diseases and mortality are a source of inequality among the elderly. An important research question central to the ongoing exploration of morbidity in the United States is whether some race-sex groups spend additional years of life in illness, while other groups spend these years in health. Sex and racial disparities in health and mortality may be partially the result of biological, social, and psychological differences including education (Freedman and Martin, 1999), occupation (Darity, 2003), income and wealth (Williams and Jackson, 2005), access to health care and information (Kreps, 2006), health behaviors (Lantz *et al.*, 1998), and social integration (Kawachi, 1999). Assessment of these sex and racial disparities in the elderly population is important for several reasons. First, the existence of disparities in healthy life is indicative of corresponding disparities in quality of life and racial inequality in health (Crimmins *et al.*, 1989, 1997; Hayward and Heron, 1999). Second, assessment of disparities is critical because they are a major public health concern affecting future demand for medical care and services (Singer and Manton, 1998) and quality of life (Cutler, 2001). Third, disparities are also an important public policy concern. The long term fiscal viability of the Social Security and Medicare programs may be affected by differential changes in health and mortality. Additional years of productive disability-free working life may contribute to favorable changes in the ratio of workers to Social Security and Medicare beneficiaries and extend the trust fund years into the future (Singer and Manton, 1998). Fewer years may contribute to greater health care expenditures and long-term care needs and present a strain on the programs.

In this paper, I address a previously unanswered question in the literature: do some race-sex groups of actual birth cohorts live not just longer lives, but longer healthier lives, while others spend additional years in illness? To answer this question, I estimate disparities in the expected remaining life in disability by sex and race in US cohorts born between 1904 and 1909. Estimation is based on a newly developed extension of Sullivan's method to birth cohorts (Imai and Soneji, 2007) and a refined definition of physical disability (Verbrugge and Jette, 1994) using data from both community and institutionalized Medicare recipients. Estimation of the expected years of life in disability by level of severity along with total expected years of life allows assessment of whether additional years of life are spent in illness (morbidity expansion) or in health (morbidity compression). In particular, I examine whether racial and sex disparities exist in the expected years of life in disability by level of severity and discuss implications to disparities in morbidity compression and expansion.

Competing theories of morbidity compression and expansion have become increasingly important over the $20th$ century as mortality rates significantly dropped in developed nations, causing dramatic increases in life expectancy. Two competing theories exist regarding whether this longer life is spent in illness and disability or in health. A cohort experiencing improvement in the ratio of age-specific healthy life expectancy and total life expectancy is indicative of morbidity compression (Fries, 1980). Alternatively, a cohort experiencing a decreasing ratio is indicative of morbidity expansion (Gruenberg, 1977; Kramer, 1980).

The vast majority of research into the theoretical understanding of and disparities in morbidity has two limitations. First, the use of cross-sectional data and hypothetical cohorts may ignore the influence of cohort effects and introduce bias (Bongaarts and Feeny, 2002). Second, the use of binary indicators of physical disability masks levels of severity and limits ability to discern different patterns in disability. In contrast, this paper focuses on the health and mortality experience of actual birth cohorts and uses an expanded definition of physical disability.

To address the first limitation, I focus on the mortality and disability experience of actual birth cohorts aging over time. In doing so, I avoid the influence of distorting cohort effects that may result from age-specific disability prevalence and mortality rates changing over time. Based on data from actual birth cohorts, I use an extension of Sullivan's method developed by Imai and Soneji (2007) to estimate the expected remaining life with disability. The new methodology provides valid estimation and does not require the assumption of constant age-specific disability prevalence and mortality rates over time.

To address the second limitation, I expand the definition of physical disability to indicate level of severity following the conceptual framework of Verbrugge and Jette (1994). I classify physical disability into mild and severe based on whether the ability to perform a physical activity is possible with some difficulty, or if there is such great difficulty that special equipment or aides are required. Classification of physical disability into mild and severe serves several purposes. First, it may distinguish levels of limitation and impairment. Second, the classification may be indicative of differences in medical care and rehabilitation. Both may be more complex and costly for the severely disabled who require greater services and experience greater morbidity.

The paper is organized as follows. In Section 2, I review largely period-based evidence of the existence of sex and racial disparities in health and mortality, leading to disparities in healthy life expectancy. I also discuss the need for similar research using actual birth cohorts. In Section 3, I introduce a distinction in physical disability indicating level of severity. I also outline an application of Sullivan's method to birth cohorts used to estimate disparities in the expected remaining life with disability. Then, in Section 4, I estimate the aforementioned expected remaining life with disability by sex and race for the 1904 to 1909 US birth cohorts. Finally, in Section 5, I discuss conclusions and implications.

2 Sex, Gender, and Racial Disparities

In this section, I discuss disparities in health and mortality that ultimately lead to disparities in the expected remaining life with and without disability. I first establish the existence of sex and racial disparities in mortality and total life expectancy. Second, I discuss similar disparities in many of the chronic conditions that often lead to physical disability. Finally, I discuss period-based evidence of disparities in healthy life expectancy and discuss the need for analogous work in actual birth cohorts.

Examination of both sex and racial disparities is important for two reasons. The evidence for these disparities between racial and ethnic groups in health status and mortality is overwhelming and cause for public health and public policy concern (Schulz *et al.*, 2000; Sudano and Baker, 2006). Additionally, a comparison by both race and sex is necessary because racial differences in health and mortality may differ in degree and possibly direction by sex (Manton and Stallard, 1997). While recognizing that both sex-linked biology and gender can independently or jointly affect health status and mortality, hereafter, I refer to both the biological construct of sex and sociological construct of gender as sex (Krieger, 2003).

2.1 Mortality and Total Life Expectancy

Studies that assess disparities in cohort life expectancy consistently show blacks experience higher mortality than whites within sex (Manton and Stallard, 1997; Parnell and Owens, 1999). Comparisons of both cohort and period life expectancy by race are difficult because the accuracy of age reported on death certificate information and population counts are often questionable, especially for older blacks (Rosenwaike, 1968; Rosenwaike and Logue, 1983; Coale and Kisker, 1990). A significant source of unreliability for these older blacks is unregistered births (Elo and Preston, 1994). A second concern of cohort life expectancy is waiting time; meaningful estimation requires the cohort to be extinct, or at least nearly extinct (Wilmoth *et al.*, 2005). As of 2006, for example, cohorts born later than 1910 still have a sizable proportion of their populations alive. Despite these data and waiting time considerations, the advantage of cohort life expectancy is that it represents the mortality experience of a real birth cohort aging over time and avoids the influence of distorting cohort effects.

Analyzing the mortality of actual birth cohorts, Manton and Stallard (1997) found racial disparities in the age and sex specific mortality rates of the 1887 and 1892 birth cohorts using the method of extinct generations. In this method, the mortality rate at a given age is equal to the ratio of the number of deaths at this age to the number of deaths at this age and all later ages in all later years for this cohort (Vincent, 1951). The method reduces the impact of age of death misstatement on death certificates by allowing the error to appear in both the numerator and denominator of the mortality rate (Johnson, 2000). It allows estimation of mortality rates and life expectancy by race and sex based solely on death certificate information, avoiding biases in census estimates of blacks.

Careful consideration of data concerns, especially age misreporting, in period-based studies have also consistently shown disparities by sex and race. Using high quality Medicare data, Kestenbaum (1992) showed a racial crossover in the 1987 period at age 90. A racial crossover implies that white mortality was lower than black mortality until this age, at which point the relationship reversed. Considering both data quality and population heterogeneity, Lynch *et al.* (2003) found the variance in the distribution of ages of death decreased with blacks, but not whites, across time. Lynch *et al.* (2003) also found that a black-white period mortality crossover existed and the age of crossover increased over time.

2.2 Chronic Diseases, Impairments and Disability

Along with racial and sex differences in disease interaction and health care, disparities in chronic conditions contribute to corresponding disparities in functional loss and disability (Smith and Kington, 1997; Hayward *et al.*, 2000). The most important chronic conditions that contribute to physical disability are osteoarthritis, stroke, heart disease, and diabetes (Guccione *et al.*, 1994). In this section, I discuss disparities in each of these chronic conditions and their importance to physical disability.

First, rheumatoid diseases, especially osteoarthritis, are the most common chronic condition and leading cause of physical limitations among female elderly (Piacavet and Hazes, 2003; Verbrugge and Juarez, 2006). In 1993, the prevalence of self-reported arthritis was 1.43 times greater in 65 – 74 year old women and and 1.25 times more greater in 75-plus year old women compared to men (Verbrugge, 1995). Among women, blacks were about twice as likely as whites to report knee osteoarthritis, controlling for age and weight. Yet among men, blacks were no more likely than whites (Anderson and Felson, 1988). Rheumatoid diseases impact the independence of older adults and is linked to higher activity limitation and incidence of physical disability (Katz, 1995; Song *et al.*, 2006).

Second, disparities in circulatory diseases such as atherosclerosis, anemia, hypertension, heart disease, and stroke are equally important. Lipoprotein(a) is associated with heart disease and stroke and shown to be much higher in black women than white in the Kaiser Permanante Women Twins Study, conducted in 1989 – 1990 (Selby *et al.*, 1994). Anemia is associated with physical disability and decreased physical performance and muscle strength (Penninx *et al.*, 2004). Guralnik *et al.* (2004) found anemia to be approximately three times as prevalent in black men (27.5%) and black women (28.0%) as white men and women (9.2% and 8.7%, respectively). In a review of twenty-five community and population level studies, Gorey and Trevisan (1998) found hypertension approximately 2.59 times more prevalent among black women than white women in studies conducted between 1960 and 1975 and 1.77 times more prevalent in studies conducted between 1976 and 1990. The prevalence of hypertension among black men compared to white men was approximately 2.20 times greater in the first half and 1.38 times greater in the later second half. In the Duke MacArthur study, Gold *et al.* (1996) found that even among the healthiest elderly studied, racial differences in hypertension persisted.

Finally, adult onset diabetes mellitus is far more prevalent in blacks than whites (Brancati *et al.*, 1996; Wray *et al.*, 2006) and the excess prevalence among blacks is greater among women than men (Robbins *et al.*, 2000). Diabetes is associated with physical disability. These disabilities are likely to substantially impair functionality and quality of life, especially during the later progression of the disease (Gregg *et al.*, 2000).

Along with racial and sex disparities in disease interaction and health care, disparities in the chronic conditions discussed in this section likely contribute to corresponding disparities in functional loss and disability. Crimmins (2004) argues the most severe physical disability is an inability to provide self-care and is measured by activities of daily living (ADL) including: bathing or showering, dressing, eating, getting in or out of bed or chairs, walking, and using the toilet. Examining five waves of the National Long Term Care Survey from 1982 to 1999, Arbeev *et al.* (2004) found the highest ADL disability prevalence among 70+ year olds in black women (22.49% to 26.81%) followed by white women (16.38% to 17.99%). ADL disability prevalence for black and white men was significantly lower, 15.81% to 22.50% and 10.22% to 12.50%, respectively. While disparities in these chronic conditions are a significant societal concern, they alone do not indicate disparities in quality of life. To estimate this, health and mortality information can be combined into the single measure called disability life expectancy.

2.3 Disability Life Expectancy

Disparities in disability and total life expectancy may ultimately culminate in disparities in the expected remaining life with disability (disability life expectancy). Defined analogously as total life expectancy, disability life expectancy (DLE) is the expected remaining life with disability (as opposed to without disability) of an individual of a given age. period-based evidence consistently shows disparities in DLE by sex, race, and socioeconomic status factors. The proportion of remaining life in disability is lower for men (Crimmins *et al.*, 1989; Manton and Stallard, 1991), whites (Crimmins *et al.*, 1989; Hayward and Heron, 1999), the most educated (Land and Guralnik, 1994;

Crimmins and Saito, 2001; Molla *et al.*, 2004), and those who own a home (Matthews *et al.*, 2006).

Estimation of disparities in cohort DLE is important because it reflects the true health and mortality experience of cohorts aging over time. Analysis based on birth cohorts avoids the influence of cohort effects (Bongaarts and Feeny, 2002) and does not invoke tenuous stationarity assumptions in age-specific disability prevalence and age-specific mortality rates over time required in period-based estimation (Imai and Soneji, 2007).

3 Measurement of Disability and Disability Life Expectancy

In this section, I distinguish between mild and severe physical disability. I discuss the advantage of separating physical disability into these two categories. Finally, I present an overview of the methodology used to estimate the expected years of life in disability for birth cohorts.

3.1 Actual and Intrinsic Physical Disability

In this section, I expand the definition of physical disability and consider the severity of the gap between personal capability and the activity's demand. Verbrugge and Jette (1994) classify physical disability into intrinsic and actual disability based on whether an ADL is difficult to perform despite the use of special equipment or aide. This framework is conceptually useful but difficult to implement in empirical research because no national surveys ask the appropriate questions. Instead, I classify ADL disability into mild and severe based on whether the ability to perform an ADL is possible with some difficulty, or if there is such great difficulty that special equipment or aides are required. Such a classification is useful: while mild ADL disability may represent surmountable difficulty, severe ADL disability may represent significant burden and limitation requiring greater care and services.

To assess the prevalence of ADL disability by level of severity in the US population by single year of age, sex, and race (white and black), I use the the 1991 Medicare Current Beneficiary Survey (MCBS) (available through the Inter-university Consortium for Political and Social Research (ICPSR)), 1992 and 1993 MCBS Access to Care (available through the ICPSR), and 1994 to 2003 MCBS Cost and Use (available through the U.S. Department of Health and Human Services).

The MCBS is a continuous, multi-purpose survey of a representative national sample of the Medicare population. The Medicare population includes both the noninstutitionalized and the institutionalized populations and is conducted by the Centers for Medicare and Medicaid Services. Medicare is the largest health insurance program in the U.S., which covered between 95.3% and 96.5% of the U.S. population age 65 and older between the years 1991 and 2003 (DeNavas-Walt *et al.*, 2005). The use of this survey gives a complete picture of disability status for the overall U.S. population for each year. The main advantage of the MCBS over other national surveys such as the National Health Interview Survey is the inclusion of both noninstitutionalized (i.e., community) and institutionalized (i.e., nursing home) residents.

A respondent in the MCBS was considered to have an ADL disability if he/she responded affirmatively to the following question: "Because of a health or physical problem, do you have any difficulty . . . ?" where ". . . " represent ADLs. Each respondent who responded affirmatively to an ADL was also asked, "Do you use special equipment or aide to help you with . . . ?" where . . . represent a reported ADL disability. A respondent was considered to have mild disability if he/she self-reported at least one ADL, but no use of special equipment to aide or help with this ADL. Severe disability was defined as a respondent who self-reported at least one ADL and used special equipment to aide or help with this ADL. In all the anlayses presented below, the survey weights are incorporated so that respondents are approximately weighted according to their population size.

3.2 Estimation of Disability Life Expectancy from a Cohort Life Table

Disability life expectancy (DLE) is estimated using the extension of Sullivan's method to birth cohorts developed by Imai and Soneji (2007). The extension combines the disability prevalence and mortality rates of an actual birth cohort into a single summary measure of the cohort's health status. The key idea of the new method is to combine the cohort life table with age-specific disability prevalence estimated from either consecutive cross-sectional surveys or a longitudinal survey. In particular, the new method simply partitions the total number of person-years lived, which is obtained from the cohort life table, into mild and severe DLE based on the proportion with mild and severe disability, which is in turn measured from the disability surveys.

Imai and Soneji (2007) prove that the cohort-based extension of Sullivan's method provides a statistically unbiased and consistent estimator of mild and severe DLE and offers many advantages over the period-based Sullivan's method and the multi-state life table method. First, the cohort extension is based on a cohort life table, which describes the mortality experience of a real cohort of individuals from birth of the first to death of the last member of the group (Chiang, 1984). Second, the cohort extension avoids tenuous stationarity assumptions, notably constant age-specific mortality rates and age-specific disability prevalence over time (e.g., Chiang, 1984; Preston *et al.*, 2001). Third, compared to the multi-state life table method, the cohort extension of Sullivan's method avoids theoretical and data driven assumptions that may affect estimation of DLE (Imai and Soneji, 2007).

A final advantage occurs when the disabilty surveys do not cover the entire age interval. In this case, Imai and Soneji (2007) apply the method of bounds and invoke assumptions about the nature of disability. For example, mortality rates for the 1909 birth cohort are observed for ages 61 to 94 because the mortality data is available from 1970 to 2003. Using the method of extinct generations, smoothed mortality rates are estimated for even higher ages until a specified maximum age (e.g., 100), at which point the cohort is considered extinct and the life table closed. Yet, disability prevalence for this birth cohort is only available for ages 82 to 94 because the disability surveys are available from 1991 to 2003. To estimate DLE at age 95, we can bound it by considering the minimum and maximum values of the contribution of disability person years within the last age intervals not covered by the disability survey. Disability prevalence is bounded between 0 and 1 for all ages. Then, the bounds for disabled person years for these intervals are bounded by 0 and the total person years in these intervals. These bounds may not be informative in practice.

In order to further narrow the bounds, Imai and Soneji (2007) entertain an additional monotonicity assumption regarding the nature of disability for older ages. In particular, disability prevalence is assumed to increase monotonically with age. In the example, disability prevalence for ages 95 and beyond is bounded between the observed disability prevalence for age 94 and 1. Then, the new bounds for disability person years at age 95 are between the disability person years at age 94 and the total person years at age 95. Similarly, if disability surveys do not cover earlier age intervals, we can obtain the bounds of DLE using the monotonicity assumption. In particular, disability prevalence for earlier ages is no greater than the first observed disability prevalence.

It is possible to obtain the simultaneous confidence interval of the lower and upper bound of DLE using the bootstrap method (Beran, 1988). This simultaneous confidence interval is asymptotically balanced and has correct overall coverage probability given sufficient number of bootstrap replications.

For this analysis, I estimate cohort life tables for birth cohorts born between 1904 and 1909 based on mortality data collected in US Vital Statistics and mortality rates calculated by the method of extinct generations by single year of age, sex, and race. These birth cohorts are chosen for study because they experience considerable disability and mortality during the window of available data. They are also old enough to be nearly extinct at the last year of available mortality information.

I then estimate mild and severe disability prevalence by single year of age, sex, and race for these cohorts using consecutive MCBS data from 1991 to 2003. Given the variability in observed disability prevalence, I use a model-based adjustment to estimate the disability prevalence as a smooth function of age and functions of year of survey, race, and sex. In particular, I model the disability prevalence using the generalized additive model (GAM) (Hastie and Tibshirani, 1990). Finally, I combine disability prevalence and mortality rates of birth cohorts to estimate mild and severe DLE using the methodology discussed in this section.

4 Results

In this section, I address the previously unanswered question: do some race-sex groups of actual birth cohorts live not just longer lives, but longer healthier lives, while others spend additional years in mild or severe disability? In particular, I first characterize racial and sex disparities in healthy life. Second, I compare mild and severe DLE across race-sex groups, adjusting for total life expectancy. Finally, I assess the existence of compression in mild and severe disability for each group over time.

4.1 Mild and Severe Disability Life Expectancy

Racial disparities in healthy life are most evident in the differences estimated in severe DLE. While life expectancy and mild DLE were approximately equal for blacks and whites, blacks experienced significantly higher severe DLE than whites by sex. Figure 1 shows the disparities in severe DLE by race within sex for the 1908 birth cohort. For example, the lower left panel estimates that at age 83, black males lived, on average, 6.02 additional years of life. They spent between 0.84 to 1.00 of those years in mild disability and between 1.53 to 1.66 in severe disability, on average. Life expectancy at this age for white males was nearly equal (6.00 years) as was mild DLE (0.88 to 0.99). Yet, the expected time in severe disability was significantly less, 1.14 to 1.26 years. The 95%

balanced confidence intervals are estimated using the bootstrap procedure described in Section 3.2 with $2,000$ replications.

The same disparity exists between black and white females. Life expectancy and mild DLE are approximately equal while severe DLE is significantly higher for black females. The upper (lower) right panel shows life expectancy for white (black) women was 7.35 years at age 83. Mild DLE was also nearly equal–between 1.36 to 1.56 years for white women and between 1.38 to 1.51 years for black women at age 83. Yet, black women experienced significantly higher severe DLE compared to white women. At age 83, severe DLE for black women was between 2.41 to 2.52 years while only between 1.82 to 1.99 years for white women. The results indicate severe and debilitating disability may be a more important part of the aging experience for blacks than for whites.

4.2 Proportion of Remaining Life Spent in Mild and Severe Disability

Black females may be the most disadvantaged race-sex group and experience the most severe DLE. In order to examine sex and racial disparities in mild and severe DLE, adjusting for total life expectancy, I introduce two additional quantities of interest: the proportion of remaining life spent in mild disability and the proportion of remaining life spent in severe disability. Figure 2 shows the proportion of remaining life spent in mild disability, severe disability, and free of either disability for the 1908 birth cohort. While both the proportion of remaining life spent in severe disability and the proportion in mild disability increase over age for all groups, the increase is less for the former than the latter. For example, the lower left (right) panel shows these proportions for black males (females). From age 83 to 95 for black males (females), the proportion of remaining life in severe disability increased from 26.7% (33.3%) to 31.8% (38.9%). The proportion of remaining life in mild disability increased from 16.4% (20.3%) to 26.3% (30.8%). Also of note is the proportion of remaining life free of either disability. For any age considered, this proportion was highest for white males, then black males and white females. Finally, black females experienced the least proportion

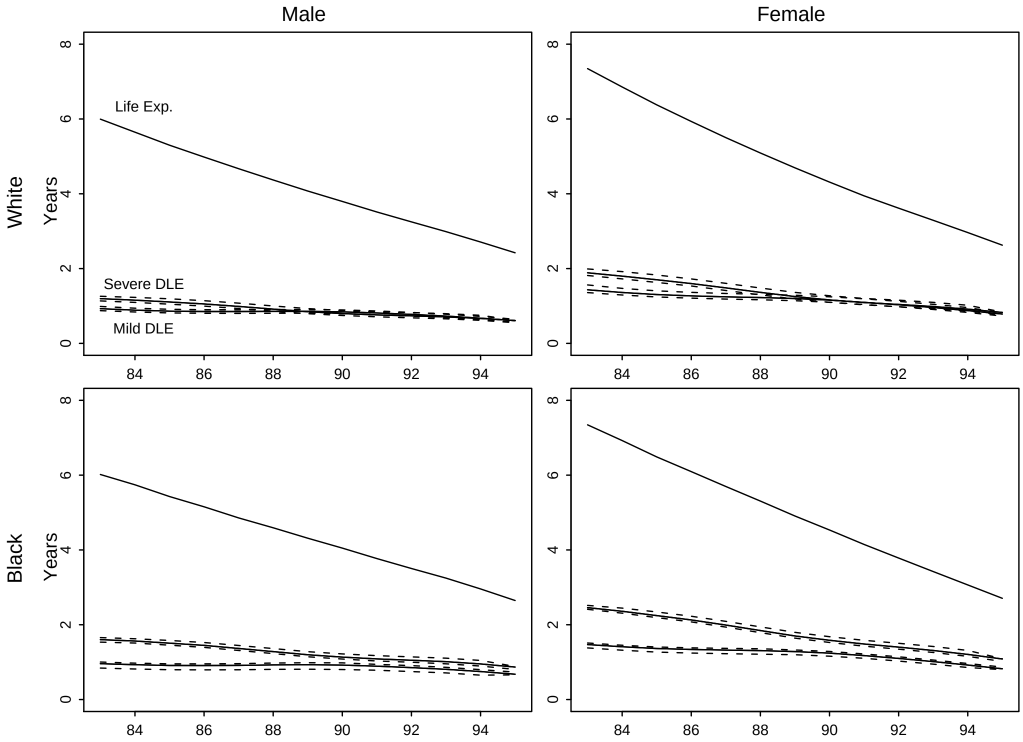

Figure 1: Life Expectancy, Mild Disability Life Expectancy, and Severe Disability Life Expectancy by Sex and Race for the 1908 Birth Cohort. Each panel show the total life expectancy and both mild and severe disabled life expectancies for a given sex and race group for the 1908 birth cohort between the ages 83 and 95. The balanced 95% confidence intervals are shown as dashed lines. (Mild disability is defined as at least one activity of daily living deficiency, but no use of special equipment. Severe disability is defined as at least one activity of daily living deficiency that does require the use of special equipment.)

of remaining life free of either disability, just an estimated 46% at age 83 compared to 65%, 57%, 55% for white males, black males, and white females, respectively.

The proportions of remaining life spent in mild and severe disability allows for comparisons among all sex and race groups as shown in Figure 3. Within sex, white males (females) experience nearly identical proportions of remaining life in mild disability, but lower proportions of remaining life in severe disability compared to black males (females). For example, compared to black males (females) at age 83, white males (females) experienced approximately 0.51% (0.46%) less of their remaining life expectancy in mild disability as seen in panel (3,1) ((4,2)). Yet, the same comparison shows white males (females) experienced approximately 7.76% (6.67%) less of their remaining life

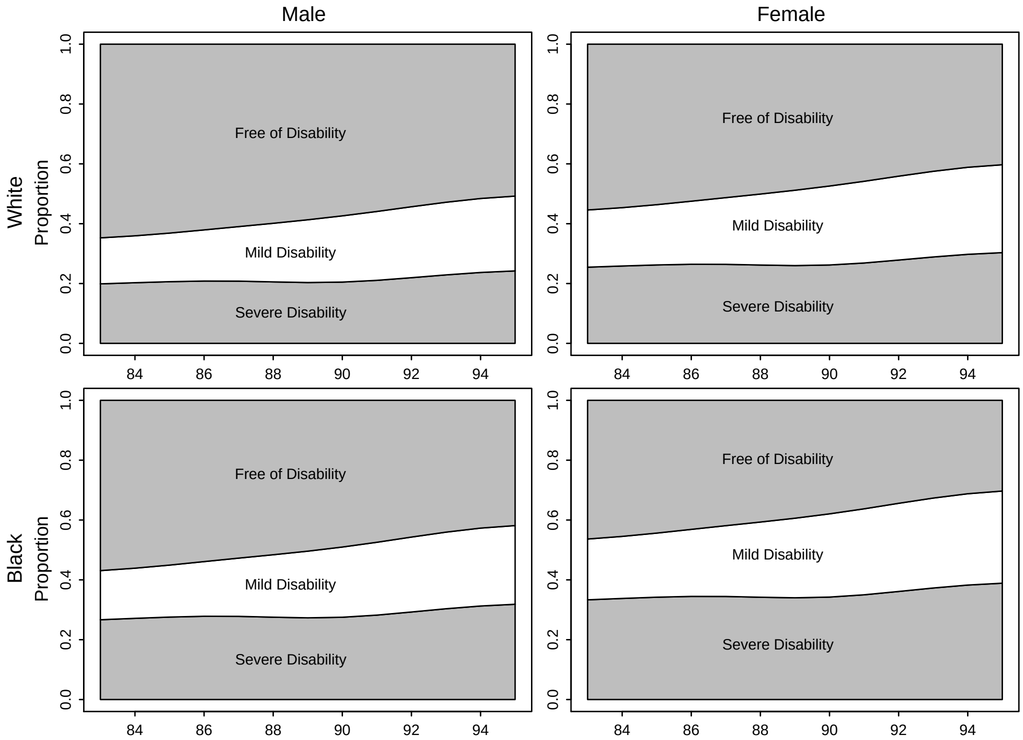

Figure 2: Proportion of Remaining Life Spent in Mild Disability, Severe Disability, and Healthy by Sex and Race for the 1908 Birth Cohort. Each panel shows the proportion of remaining life spent in mild disability, severe disability, and free of either type of disability for a given sex and race group.

expectancy in severe disability.

Within race, the difference between the proportions of remaining expected life in mild disability of white (black) males and females is nearly constant for all ages considered. The same is true for severe disability. Panel (2,1) shows white males experience approximately 4.0% less of their remaining expected life in mild disabiltiy and 6.0% less in severe disability than white females, respectively, compared to white females. For blacks, panel (4,3) shows males experience approximately 4.5% less of their remaining expected life in mild disability and 7.0% less in severe disability than females, respectively.

Comparisons across both sex and race reveal the greatest disparities. Compared to white males, black females experience a greater proportion of their remaining expected life in mild and severe disability. For example, at age 83, black females experience 4.54% more in the proportion in mild disability and 13.50% more in the proportion in severe disability as shown in panel (1,4). Compared to white females, black males also experience a greater proportion in mild disability, but nearly identical proportion in severe disability. For example, also at age 83, the proportion in mild disability was 3.57% higher but just 0.93% lower in the proportion in severe disability as shown in panel (2,3).

4.3 Changes in Disabled Life Across Cohorts

All race-sex groups experience a compression of severe disability over time, especially black women. Similar compression was not observed in mild disability. I estimate these changes in mild and severe DLE between the 1904 and 1909 birth cohorts. In the disability survey period, 1991 to 2003, the 1904 birth cohort was between 87 to 99 years old. The 1909 birth cohort was between 82 and 94 years old. I use the method of bounds (Imai and Soneji, 2007) to extend the window of comparison one year earlier and later for both cohorts. As a result, the 1904 and 1909 cohorts may be closed at the same age, 95, to allow direct comparison of total, severe disability, and mild disability life expectancies.

Figure 4 shows the bounds of improvement in severe DLE between the ages 86 and 95 for all race-sex groups. Women, especially black women, experienced the greatest improvements as seen in the upper right (white) and lower right (black) panels. At age 87, for example, black women experienced between 0.39 and 0.69 years less severe DLE in the 1909 birth cohort than experienced at the same age in the 1904 birth cohort. White women experienced similar improvements, 0.33 to 0.54 year reduction in severe DLE at age 87. White and black men experienced more modest improvements.

Similar improvements were not observed in mild DLE between the ages 86 and 95 for any race-sex group. Figure 5 shows the bounds for improvement in mild DLE for all race-sex groups.

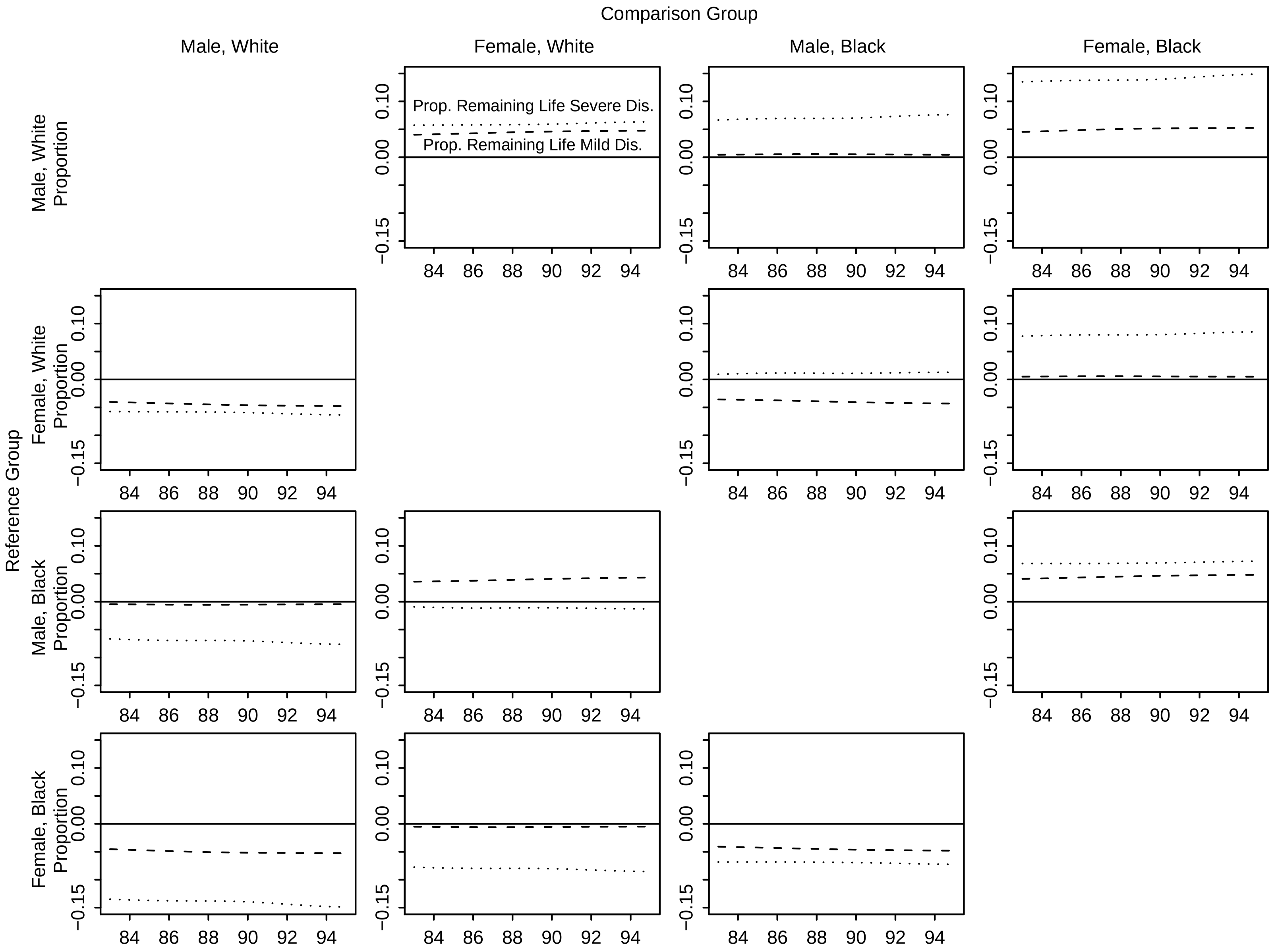

Figure 3: Differences in the Proportion of Remaining Expected Life Spent in Mild and Severe Disability by Sex and Race for the 1908 Birth Cohort. Each panel compares the difference in the proportion of remaining expected life spent in mild disability (dashed line) and in severe disability (dotted line) of one sex and race group to another.

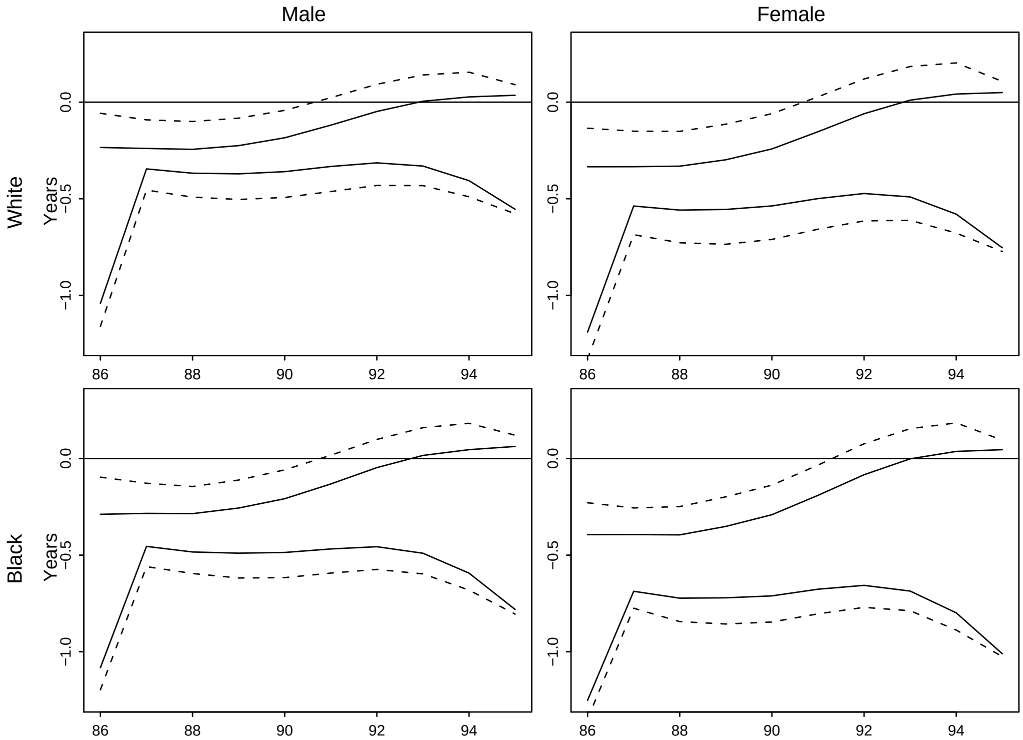

Figure 4: Change in Severe Disability Life Expectancy Between the 1904 and 1909 Birth Cohorts By Sex and Race. Each panel shows the change in mild disability life expectancy between the 1904 and 1909 birth cohorts over the ages 86 to 95. The monotonicity assumption is invoked one year before and after.

Age-specific mild DLE does not improve significantly over the six year period between the cohorts.

The differential improvement observed in mild and severe DLE by race and sex is due to a combination of changes in both age-specific mortality rates and age-specific disability prevalence. Figure 6 compares the mortality rate and disability prevalence for common ages of the two cohorts. Mortality rates for all groups are nearly stationary and, therefore, total life expectancy does not change over time. The age-specific mild disability prevalence of all race-sex groups increased slightly from the older 1904 cohort to the younger 1909 cohort. All groups experience considerable decline in age-specific severe disability prevalence over time. Over time, black women experience the highest absolute age-specific prevalence of severe disability and the highest relative improvement of all race-sex groups.

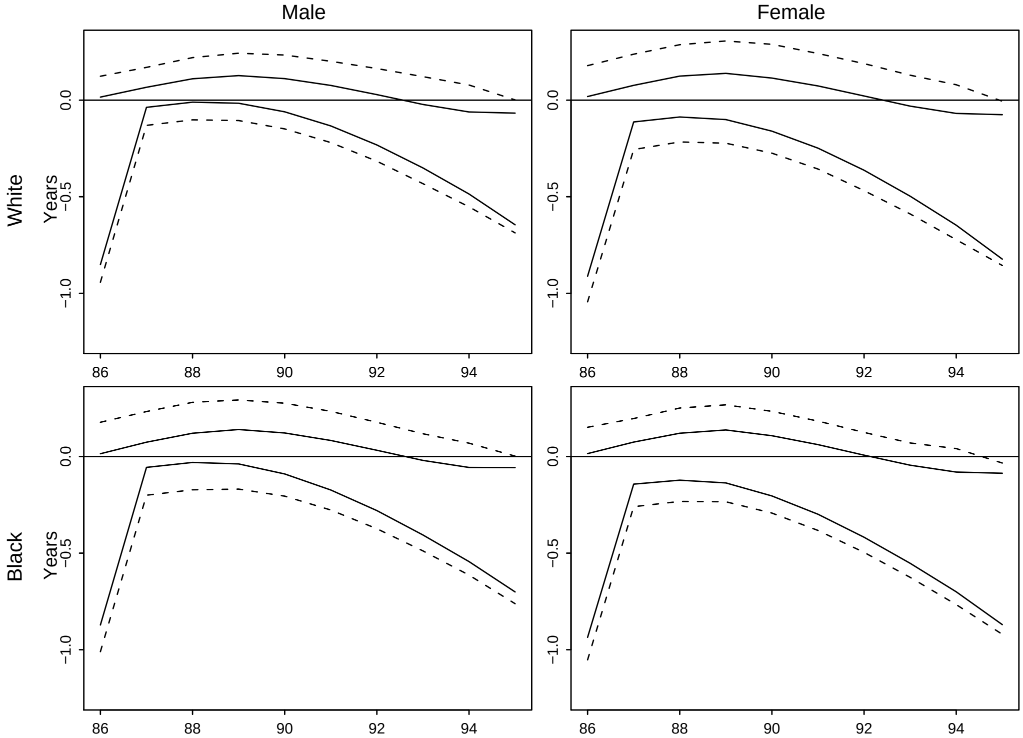

Figure 5: Change in Mild Disability Life Expectancy Between the 1904 and 1909 Birth Cohorts By Sex and Race. Each panel shows the change in mild disability life expectancy between the 1904 and 1909 birth cohorts over the ages 86 to 95. The monotonicity assumption is invoked one year before and after.

5 Concluding Remarks

This article addresses the following research question. Do some race-sex groups of actual birth cohorts live not just longer lives, but longer healthier lives, while others spend additional years in mild or severe disability? The analysis reveals several important findings related to this question, possible through the refined definition of physical disability and new extension of Sullivan's method to birth cohorts. The refined definition allows finer gradation of physical disability and more detailed observation of racial patterns. The new extension of Sullivan's method provides a statistically unbiased and consistent estimator of mild and severe DLE using the disability and mortality experience of actual birth cohorts aging over time.

First, use of a refined definition of physical disability provides evidence for both sides of the

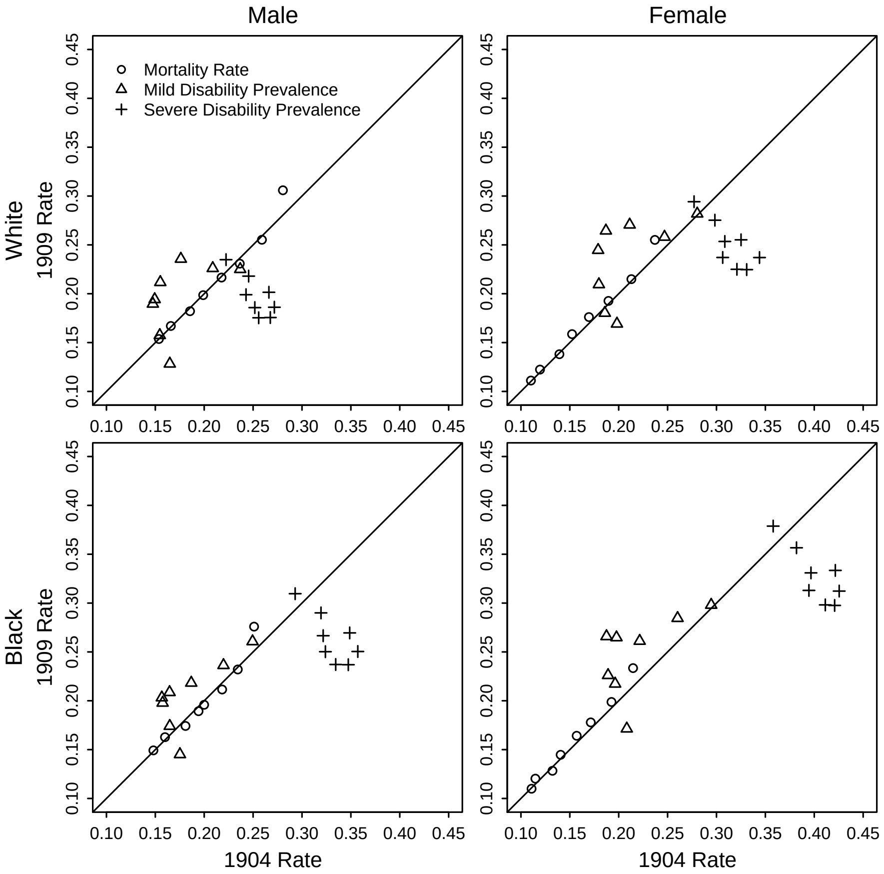

Figure 6: Mortality Rates, Mild Disability Prevalence, and Severe Disability Prevalence by Sex and Race for the 1904 and 1909 Birth Cohorts. Each panel plots 1904 mortality rates versus 1909 mortality rates (circle), 1904 mild disability prevalence versus 1909 mild disability prevalence (triangle), and 1904 severe disability prevalence versus 1909 severe disability prevalence (plus sign) for ages 87 to 94.

debate on the existence of a racial disability gap (Kelley-Moore and Ferraro, 2004). Racial disparity in severe DLE persists for all ages studied. By sex, blacks experience significantly greater years of severe DLE than whites. This result provides evidence in support of persistent health inequality advocated by Ferraro (1987). On the other hand, no discernible racial disparity in mild DLE was present. By sex, blacks and whites experience approximately equal years of mild DLE. This result is consistent with the findings of approximately equal sex-specific disability life expectancy between whites and blacks (Guralnik *et al.*, 1993). Both sets of findings indicate the nature of disability may be far worse for blacks, especially black women.

Second, although total life expectancy is approximately equal, blacks experience many more years of severe DLE than whites. Consequently, the proportion of remaining life without either mild or severe disability is much greater for blacks. Consistent with previous findings, blacks and especially black women experience the worst quality of remaining life (Hayward and Heron, 1999). Such disparities in quality are the result of differences in chronic diseases, disability, and mortality. These disparities provide evidence for the existence of racial inequality in health and indicate the greatest need for medical care and services may be among black women.

Third, compression of severe disability is greatest for black women and evident for all race-sex groups in direct support of the compression of morbidity hypothesis (Fries, 1980). No corresponding compression of mild disability was found for any race-sex group. The primary reason for the compression of severe disability in all race-sex groups is the combination of nearly stationary age-specific mortality rates and decreasing age-specific severe disability prevalence over time. Compression of severe disability, without compression of mild disability, indicates the nature of disability may be changing over time. Blacks, especially black women, may continue to experience the most severe disability. But the experience may become increasingly compressed into the last few years of remaining life.

The present study provides a basis for future work in racial disparities in healthy life. Additional years of disability survey would allow a wider age window for analysis and assessment of compression over a greater span of time.

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