Aging Successfully until Death in Old Age: Opportunities for Increasing Active Life Expectancy

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The purpose of this study was to estimate the prevalence of having no disability in the year prior to death in very old age and to examine factors associated with this outcome. Participants were men and women aged 65 years and older who were followed prospectively between 1981 and 1991 from three communities: New Haven, Connecticut; Iowa and Washington counties, Iowa; and East Boston, Massachusetts. Persons who died in late old age with known disability status within 15 months of death (n = 1,097) were studied for predictors of dying without disability at the last follow-up interview prior to death. The probability of a nondisabled 65-year-old man’s surviving to age 80 and then being nondisabled prior to death was 26% and, for a 65-year-old woman, the probability of surviving to age 85 and being nondisabled before death was 18%. Physical activity was a key factor predicting nondisability before death. There was nearly a twofold increased likelihood of dying without disability among the most physically active group compared with sedentary adults (adjusted odds ratio = 1.86, 95% confidence interval 1.24–2.79). These findings provide encouraging evidence that disability prior to death is not an inevitable part of a long life but may be prevented by moderate physical activity. Am J Epidemiol 1999; 149:654–64.

activities of daily living; aged; body mass index; disabled; exercise; health behavior; mortality; smoking

When people survive to old age, fear of death is often replaced by fears of disability or institutionalization (1). It was estimated that, in 1994, 37 percent of men and 55 percent of women aged 85 years and older were either living in an institution or living at home with help from another person to perform daily activities (2). The total costs of caring for a disabled older adult in the community have been estimated at $9,600 annually (3). This estimate is far exceeded by the cost of institutional care that is approximately $30,000 annually (4). Research progress has led to the identification of risk factors for disability in older adults, including physical inactivity, obesity, and smoking, whose modification could potentially reduce the burden of disability (5–8).

Although these findings have been accompanied by great optimism about improving the quality of life for our growing population of older persons, reports on active life expectancy, a measure of years of disability-free life, have raised concerns that, in the face of continued increases in total life expectancy, an extension of the period of disability prior to death may be an inevitable consequence of living to advanced old age (9, 10). Medical advances that lead to delays in mortality do not necessarily have an impact on nonlethal chronic diseases that can play an important role in causing disability at very old age. Population models suggest that reductions in disabled life expectancy are only predicted to occur when morbidity is reduced at a faster rate than mortality (11). The key to reducing years of disability at the end of life may be in the prevention and treatment of chronic disabling diseases, such as arthritis (12).

Although the proportion of people over age 65 who are disabled may have declined somewhat in the past decade, the actual numbers of disabled older persons will continue to increase with the dramatic growth of the older population that will occur in the next century (2, 13, 14). Thus, it is imperative that we start to explore ways of reducing disabled life expectancy and maximizing active life expectancy in old age. When queried about how they want to live and die, most people express a desire to live a long and vigorous life and then to die quickly with little suffering at advanced old age. While this may be an ideal personal goal that would also enormously reduce the burden on the
health care system, there are only anecdotal reports about factors contributing to this scenario. In this report, we examine factors that are associated with living to an advanced old age and then dying with little or no disability.

**MATERIALS AND METHODS**

**Study population**

Subjects were participants from three sites of the Established Populations for Epidemiologic Studies of the Elderly (EPESE): East Boston, Massachusetts; New Haven, Connecticut; and Iowa and Washington counties, Iowa (n=10,294). Baseline interviews for EPESE were conducted between 1981 and 1983, followed by up to seven annual interviews. Details on the design and methods of EPESE have been published previously (15). In order to examine predictors of dying without antemortem disability, we identified the subset of persons who were not disabled at baseline, who died in very old age, and for whom we had recent follow-up information prior to their deaths. Mortality information was derived primarily from death certificates, with additional information obtained from obituaries and proxy interviews. The subject selection process is shown in figure 1. Of the 4,149 persons who died during follow-up, all persons whose age at death was ≥85 years for women or ≥80 years for men were included (ineligible = 2,147). The 457 persons who died or dropped out within the first 2 years of follow-up were excluded. Additional exclusions were 30 persons whose date of death was later than 15 months after their last annual follow-up assessment, 66 people who had missing disability data on their last follow-up examination, and 352 persons who were disabled in activities of daily living at baseline. The final study sample included 610 men and 487 women.

Two years of study participation were required in order to exclude persons who were near death or had unstable health at baseline. The average follow-up time of the decedents was 6.1 years (range, 2–8 years).

![Figure 1](image.png)

**FIGURE 1.** Subject selection. EPESE, Established Populations for Epidemiologic Studies of the Elderly; ADL, activities of daily living.
The decedent cohort was restricted to those who were not disabled at baseline, since disability at baseline could influence baseline behaviors, such as smoking and physical activity. Age at death eligibility criteria differed by sex because of differences in life expectancies for men and women. The 15-month inclusion criterion was applied because the annual examinations were sometimes delayed up to 3 months after the 12-month anniversary date of the previous examination. The study cohort was compared with the older survivors (i.e., men who were over age 80 and women who were over age 85 and alive at the end of the 8-year follow-up). Survivors were younger, more likely to be female, and never smokers, who had a higher body mass index and were more physically active than their counterparts who died during the study follow-up (table 1).

Disability measure

Disability status was determined at each follow-up from the following question: “At the present time do you need help with (bathing, eating, dressing, transferring from a bed to a chair, using the toilet, or walking across a small room)?” If participants answered yes to needing help with or were unable to perform any of the six activities of daily living tasks, they were classified as disabled in activities of daily living for that annual examination. If participants needed help with activities of daily living in the last examination prior to death, they were classified as disabled prior to death (n = 655). If they reported no activities of daily living disability at the last follow-up examination prior to death, they were considered not disabled prior to death (n = 442).

Potential risk factors

Demographic characteristics, including education, income, marital status, race, and risk factors for disability, were assessed in the baseline EPESE interview. Body mass index was calculated as the self-reported weight (kg)/height (m)$^2$ and then classified in three categories: <21, 21–27, and >27 kg/m$^2$. Smoking status was assessed by questions on current and past regular cigarette smoking. Alcohol consumption was measured by the reported frequency and amount of wine, beer, and liquor consumed in the previous month. Alcohol intake was categorized into four exclusive groups: none in 1 year, none in 1 month, <1 oz/day, ≥1 oz/day (1 oz = 30 ml) (16, 17).

A three-level physical activity variable was derived from the summed frequency of reported walking, gardening, and vigorous exercise based on an approach reported previously (8). The frequency of each type of activity was scored as follows: frequently or several times per week = 2; sometimes or weekly or several times per month = 1; rarely or never or once a month or less = 0. Scores were summed across the three activities, and the summary variable was grouped into approximate tertiles by scores of 0 (low), 1–2 (moderate), and 3–6 (high).

Self-rated health was measured by the question, “Compared to other people your age, would you say your health is excellent, good, fair, poor, or bad?” Chronic conditions were assessed by self-report. Prevalent angina was determined from a set of questions on pain, pressure, or heaviness in the chest with walking uphill or on level ground, which has been shown to be comparable to the Rose questionnaire in predicting heart disease mortality (18).

Statistical analysis

Initially, we conducted an analysis to determine the overall probability of surviving to age 80 for men and age 85 for women and then dying without disability. Probabilities were estimated according to strata of three modifiable risk factors for mortality: education, smoking, and physical activity. We used data from all EPESE participants in the three communities, excluding persons who were disabled at baseline or had missing baseline disability information (n = 8,927). The probability of surviving to age 80 for men and to age 85 for women was calculated from the time of study enrollment (1981–1983) until December 31, 1992, the final follow-up date of complete ascertainment of vital status. A truncated Kaplan-Meier product limit method was used in an Egret statistical package (Statistics and Epidemiology Research Corporation, Seattle, Washington) to calculate estimated survival probabilities for 65-year-old men to live to age 80 and for 65-year-old women to live to age 85 by using age at entry and age at exit from the cohort (19, 20). Probabilities were calculated within strata of education (≤8 years, 9–12, >12 years), smoking status (current, past, never), and physical activity level at baseline. The overall probability of a 65-year-old person’s surviving to age 80 (men) or 85 (women) and then being nondisabled prior to death was calculated as the product of the probability of surviving to age 80 or 85 and the probability of having no antemortem disability, conditional on survival.

Demographic characteristics and other risk factors are shown according to disability status prior to death. Differences between the decedent groups were tested using chi-square methods. Multivariate logistic regression modeling was performed to identify independent predictors of being nondisabled prior to death in very old age. An odds ratio greater than 1.0 is interpreted as greater likelihood of being nondisabled prior to death.
TABLE 1. Baseline characteristics of decedents and survivors, among those not disabled at baseline and age 80 or older (men) or age 85 or older (women) at the end of the study follow-up, Established Populations for Epidemiologic Studies of the Elderly cohorts, 1981–1983

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Decedents (n = 1,097)</th>
<th>Survivors (n = 1,831)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;75</td>
<td>60</td>
<td>9.8</td>
</tr>
<tr>
<td>75–79</td>
<td>252</td>
<td>41.3</td>
</tr>
<tr>
<td>80–84</td>
<td>189</td>
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</tr>
<tr>
<td>85–89</td>
<td>93</td>
<td>15.2</td>
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<tr>
<td>&gt;90</td>
<td>36</td>
<td>5.9</td>
</tr>
<tr>
<td>Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75–79</td>
<td>83</td>
<td>17.0</td>
</tr>
<tr>
<td>80–84</td>
<td>202</td>
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<tr>
<td>≥90</td>
<td>56</td>
<td>11.5</td>
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<tr>
<td>Sex</td>
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<td></td>
</tr>
<tr>
<td>Female</td>
<td>487</td>
<td>44.4</td>
</tr>
<tr>
<td>Male</td>
<td>610</td>
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<td>30.1</td>
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<tr>
<td>&gt;12 years</td>
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<td>Body mass index (kg/m²)</td>
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<tr>
<td>&lt;21</td>
<td>190</td>
<td>20.2</td>
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<tr>
<td>21–27</td>
<td>541</td>
<td>57.4</td>
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<tr>
<td>&gt;27</td>
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<td>22.4</td>
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<tr>
<td>Missing</td>
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<tr>
<td>Smoking</td>
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<td></td>
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<tr>
<td>Current</td>
<td>121</td>
<td>11.1</td>
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<tr>
<td>Past</td>
<td>323</td>
<td>29.6</td>
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<tr>
<td>Never</td>
<td>647</td>
<td>59.3</td>
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<tr>
<td>Alcohol</td>
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<tr>
<td>None in past year</td>
<td>543</td>
<td>52.1</td>
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<tr>
<td>None in past month</td>
<td>140</td>
<td>13.4</td>
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<tr>
<td>&lt;1 ounce/day†</td>
<td>314</td>
<td>30.1</td>
</tr>
<tr>
<td>≥1 ounce/day</td>
<td>46</td>
<td>4.4</td>
</tr>
<tr>
<td>Physical activity</td>
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<tr>
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<td>228</td>
<td>22.6</td>
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<tr>
<td>Moderate</td>
<td>466</td>
<td>46.3</td>
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<tr>
<td>Active</td>
<td>313</td>
<td>31.1</td>
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<tr>
<td>Missing</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Disabled in last follow-up</td>
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<td></td>
</tr>
<tr>
<td>Yes</td>
<td>655</td>
<td>59.7</td>
</tr>
<tr>
<td>No</td>
<td>442</td>
<td>40.3</td>
</tr>
</tbody>
</table>

* p < 0.05, ** p < 0.01, *** p < 0.001 (chi-square test for between-group differences).
† One ounce = 30 ml.

Death and Disability Three models were performed. The initial model included demographic, health, and self-reported medical conditions as potential predictors and did not include age at death. Model 2 included all previous variables, and age at death was added. The third and final model included only significant predictors from the second model. Adjusting for length of time in the study, that is, the time from baseline until death, did not materially change the findings, so this variable was not included in the models presented.

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Physical activity was a key modifiable risk factor that independently predicted disability status prior to death. To further investigate the association between physical activity and being nondisabled prior to death, we fit stratified models based on EPESE site, sex, age at death (<90 years, ≥90 years), and smoking status. Within each stratum, chi-square tests for trend (1 df) were performed using the three-level physical activity variable as an ordinal measure.

RESULTS

Survival to very old age

The probability of a nondisabled 65-year-old man’s surviving to age 80 was 54 percent and, for a nondisabled 65-year-old woman to survive to age 85, it was 60 percent. Survival probabilities were examined within strata of three key factors that have been found to be associated with mortality: education, smoking, and physical activity. Survival varied substantially by smoking status and physical activity level (table 2). In both sexes, current smokers had markedly lower survival than did never smokers (42 percent vs. >65 percent). Survival in past smokers was intermediate (approximately 50 percent). Similar differences were observed among physical activity levels. Approximately two thirds of those who had high levels of physical activity at baseline survived to ages 80 (men) or 85 (women), while one third of men and just under half of the women who were least active survived to the target ages. Modest differences in survival across education levels were seen in men, with 49 percent of those who reported 8 or fewer years of education surviving to age 80 versus 60 percent in their counterparts with 12 or more years of education. Essentially no differences in survival were seen across education levels in these older women.

TABLE 2. Percent probabilities* of surviving to age 80 (men) or 85 (women) for nondisabled 65-year-old men and women, probability of dying without disability after age 80 (men) or age 85 (women), and overall probabilities of a nondisabled 65-year-old person’s living to late old age and dying without disability, according to baseline education, smoking, and physical activity levels, Established Populations for Epidemiologic Studies of the Elderly (EPESE) cohorts, 1981–1991

<table>
<thead>
<tr>
<th>Education</th>
<th>Men (%)</th>
<th>Women (%)</th>
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</thead>
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<tr>
<td>58 years</td>
<td>Survival to age 80 years*</td>
<td>Death at ≥80 years without disability</td>
</tr>
<tr>
<td>9–12 years</td>
<td>56</td>
<td>52</td>
</tr>
<tr>
<td>&gt;12 years</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>68</td>
<td>49</td>
</tr>
<tr>
<td>Past</td>
<td>52</td>
<td>46</td>
</tr>
<tr>
<td>Current</td>
<td>42</td>
<td>55</td>
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<tr>
<td>Activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>34</td>
<td>43</td>
</tr>
<tr>
<td>Medium</td>
<td>48</td>
<td>45</td>
</tr>
<tr>
<td>High</td>
<td>63</td>
<td>58</td>
</tr>
</tbody>
</table>

* Survival probabilities calculated from data on all EPESE participants of East Boston, New Haven, and Iowa sites who were nondisabled at baseline (n = 8,927); Kaplan-Meier product limit estimates using the Egret program.
† Of those nondisabled at baseline, the proportion who died without activities of daily living disability of those who died after age 80 (men, n = 610) or age 85 (women, n = 487).
‡ Product of the previous two columns shows the probability of a nondisabled 65-year-old man’s surviving to age 80 and then dying without activities of daily living disability after age 80, or for a nondisabled 65-year-old woman’s surviving to age 85 and then dying without activities of daily living disability after age 85.

Probability of dying without disability in late old age

The number of years of education was only weakly associated with disability status before death in women and men (table 2). Differences were observed according to smoking status, with higher proportions of current smokers versus nonsmokers being nondisabled before death. The association was somewhat more pronounced in women than in men (in women, 43 percent of smokers vs. 28 percent of nonsmokers; in men, 55 percent of smokers vs. 49 percent of nonsmokers). The largest consistent differences in the proportions who died without antemortem disability were seen...
among levels of physical activity. Among the most physically active men, 58 percent were not disabled before death, compared with 43 percent of their least active counterparts. In women, there was a twofold difference between the highest and lowest activity groups (41 percent vs. 22 percent). In both sexes, the intermediate levels of physical activity were within the range of the two extremes.

**Combined probabilities of survival to very old age and dying without disability**

Nondisabled 65-year-old men had a 26 percent likelihood of surviving to age 80 and then being nondisabled prior to death. Among nondisabled 65-year-old women, there was an 18 percent probability of surviving to age 85 and then being nondisabled in the year prior to death. The combined probability estimates were highest in those who were the most physically active at baseline (37 percent, men; 29 percent, women; table 2). In women, this proportion was nearly three times greater than that of the least physically active women, of whom only 10 percent survived to age 85 and then died without disability. Among the least active men, only 15 percent survived to age 80 and were nondisabled before death. Although smokers who died at old age had a lower risk of disability prior to death than did nonsmokers, their survival to old age was much lower than that of nonsmokers, so their overall probability of surviving to very old ages and then dying without disability was lower than that of never smokers among the men (23 percent vs. 33 percent). In women, there was no material difference in the probability of dying without disability between current and never smokers (18–20 percent of each). The overall benefit of education was observed in men, but little difference was seen across education levels in women. In men, 30 percent of those with more than 12 years of education survived to age 80 and then died without disability compared with 23 percent of men with less than 8 years of education. Respectively, in women, the percentages were 20 percent versus 18 percent.

**Characteristics of decedents**

Overall, 49 percent of the men who died after age 80 and 30 percent of the women who died after age 85 were nondisabled in the year prior to death. There were marked differences in demographic and health characteristics between persons who were nondisabled prior to death compared with those who had activities of daily living disability according to sex (table 3). Persons who were nondisabled before death were more likely to be male, younger, nonwhite, and physically active, and they were more likely to report excellent or good health at baseline compared with their counter-

### Table 3. Baseline characteristics and risk factors of decedents by sex and disability status at last follow-up prior to death in late old age, Established Populations for Epidemiologic Studies of the Elderly cohorts, 1981–1983

<table>
<thead>
<tr>
<th></th>
<th>Women (%)</th>
<th>Men (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Able (n = 144)</td>
<td>Disabled (n = 343)</td>
</tr>
<tr>
<td><strong>Site</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Boston, MA</td>
<td>25.0</td>
<td>20.1</td>
</tr>
<tr>
<td>Iowa</td>
<td>39.6</td>
<td>51.0</td>
</tr>
<tr>
<td>New Haven, CT</td>
<td>35.4</td>
<td>28.9</td>
</tr>
<tr>
<td><strong>Age (years)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;75</td>
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</tr>
<tr>
<td>75–79</td>
<td>25.0</td>
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<td>80–84</td>
<td>44.4</td>
<td>40.2</td>
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<tr>
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<td>≥90</td>
<td>6.9</td>
<td>13.4**</td>
</tr>
<tr>
<td><strong>Race†</strong></td>
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<tr>
<td>White</td>
<td>90.6</td>
<td>96.3</td>
</tr>
<tr>
<td>Black</td>
<td>8.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Other</td>
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<td>0.0*</td>
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<tr>
<td><strong>Education</strong></td>
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<td>&lt;8 years</td>
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<tr>
<td>&gt;12 years</td>
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<td>12.5</td>
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<tr>
<td><strong>Body mass index</strong></td>
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<td>(kg/m²)</td>
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<tr>
<td>&lt;21</td>
<td>26.9</td>
<td>29.1</td>
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<tr>
<td>21–27</td>
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<td>49.4</td>
</tr>
<tr>
<td>&gt;27</td>
<td>17.8</td>
<td>21.5</td>
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<tr>
<td><strong>Smoking</strong></td>
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<tr>
<td>Current</td>
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<td>3.5</td>
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<tr>
<td>Never</td>
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<td>89.7</td>
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<tr>
<td><strong>Alcohol</strong></td>
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<td>70.6</td>
</tr>
<tr>
<td>None in past month</td>
<td>17.0</td>
<td>9.8</td>
</tr>
<tr>
<td>&lt;1 ounce/day‡</td>
<td>25.5</td>
<td>19.0</td>
</tr>
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<td>≥1 ounce/day‡</td>
<td>1.4</td>
<td>0.6*</td>
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<tr>
<td><strong>Physical activity</strong></td>
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<tr>
<td>Moderate</td>
<td>51.4</td>
<td>45.4</td>
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<tr>
<td>Active</td>
<td>25.4</td>
<td>16.7**</td>
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<td><strong>Self-rated health</strong></td>
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<tr>
<td>Excellent/good</td>
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<td>63.0</td>
</tr>
<tr>
<td>Fair/poor/bad</td>
<td>29.2</td>
<td>37.0</td>
</tr>
</tbody>
</table>

* p < 0.05, ** p < 0.01, *** p < 0.001 (chi-square test for between-group differences).
† Data on race were available for New Haven and Iowa only; data on race were unavailable for East Boston.
‡ One ounce = 30 ml.
parts with antemortem disability. Education, body mass index, and smoking status were not significantly different according to disability status prior to death within sex groups.

Predictors of dying without disability

Predictors of dying without disability were examined in multivariate models of demographic and health characteristics (table 4). In the first model, which was unadjusted for age at death, significant predictors of dying without disability included male sex, nonwhite race, high levels of physical activity, history of cancer or stroke, and urinary incontinence. When age was added to the model, cancer was no longer a significant predictor, though a high body mass index and self-rated health were significantly associated with being nondisabled before death. The final model, which included only the significant predictors from model 2, showed that each additional year of older age at death was associated with an 11 percent lower likelihood of being free from activities of daily living disability prior to death (odds ratio (OR) = 0.63, 95 percent confidence interval (CI) 0.44–0.89). Persons with fair or poor health compared with good or excellent self-rated health at baseline were two thirds as likely to be nondisabled prior to death compared with those who not only were free from activities of daily living disability at baseline, but also needed no help with walking a half mile (0.8 km) or climbing stairs (n = 745). The findings were similar to those presented above. After adjusting for age at death, sex, and EPESE site, we found that the highest level of physical activity was associated with nearly twice the likelihood of having no activities of daily living disability prior to death (OR = 0.63, 95 percent CI 0.44–0.89). Higher levels of physical activity nearly doubled the likelihood of being free from activities of daily living disability prior to death (OR = 1.86, 95 percent CI 1.24–2.79). Persons with fair or poor health compared with good or excellent self-rated health at baseline were two thirds as likely to be nondisabled prior to death (OR = 0.67, 95 percent CI 0.50–0.89). Of several health conditions, stroke and urinary incontinence were the only independent predictors of disability prior to death after adjusting for other variables.

In a more thorough examination of the benefits of physical activity, effects were examined within strata of age at death, sex, EPESE site, and smoking. Adjusting for age at death and sex, we found that high versus low levels of physical activity were associated with an increased likelihood of being nondisabled before death in each of the three EPESE populations (table 5). Both men and women benefitted from exercise, with an approximate doubling of the likelihood of being nondisabled prior to death compared with their sedentary counterparts in each sex group. The protective physical activity effect was strong in persons who died before age 90 (comparing high with low activity levels, OR = 2.43, 95 percent CI 1.52–3.88). In persons aged 90 years and older, no significant benefit was observed; however, the odds ratios were in the direction of a possible benefit. The odds ratios for exercise levels in past and never smokers were similar, with the most active seniors receiving approximately two and one-half times the protection from disability compared with sedentary older adults. Current smokers, however, did not sustain any substantial benefit from exercise, comparing high with low physical activity levels (OR = 1.18, 95 percent CI 0.39–3.54).

The test for interaction between smoking and physical activity was not significant (p = 0.17). Borderline significance to very strong trends (p = 0.06–0.0001) for increased protection from antemortem disability with greater physical activity were observed in all strata except in persons over age 90 (p = 0.38) and among current smokers (p = 0.77).

The relation between physical activity at baseline and disability status prior to death in old age was examined further in a more restricted study group limited to those who not only were free from activities of daily living disability at baseline, but also needed no help with walking a half mile (0.8 km) or climbing stairs (n = 745). The findings were similar to those presented above. After adjusting for age at death, sex, and EPESE site, we found that the highest level of physical activity was associated with nearly twice the likelihood of having no activities of daily living disability prior to death than that of the least active persons (OR = 1.89, 95 percent CI 1.12–3.20). The intermediate level of physical activity offered no clear advantage over inactivity (OR = 1.25, 95 percent CI 0.75–2.07).

DISCUSSION

The most promising findings from this research suggest that physical activity can reduce the risk of disability prior to death among those who survive to very old age. The association was found when deaths occurring within 2 years of baseline were excluded and was observed in all EPESE sites and in both sexes. In addition, older persons who were physically active were more likely to survive to very old age, resulting in a combined effect of longer life with lower risk for disability before death. Although many studies have found health benefits from physical activity, including reduced risk for disability in older adults, no known previous research has identified physical activity as a factor that could potentially lead to a shorter period of disability at the end of a long life.
### TABLE 4. Predictors of being nondisabled prior to death in very old age among decedents (n = 1,097) aged 80 years or older (men) and 85 years and older (women), Established Populations for Epidemiologic Studies of the Elderly (EPESE) cohorts, 1981–1991

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1</th>
<th></th>
<th>Model 2</th>
<th></th>
<th>Model 3*</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR†</td>
<td>95% CI†</td>
<td>OR</td>
<td>95% CI</td>
<td>OR</td>
<td>95% CI</td>
</tr>
<tr>
<td>Age at death (per year)</td>
<td>0.89</td>
<td>0.86–0.92</td>
<td>0.89</td>
<td>0.86–0.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (female vs. male)</td>
<td>0.58</td>
<td>0.40–0.85</td>
<td>0.69</td>
<td>0.47–1.01</td>
<td>0.76</td>
<td>0.56–1.03</td>
</tr>
<tr>
<td>Married</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Widowed/divorced</td>
<td>0.91</td>
<td>0.66–1.25</td>
<td>1.08</td>
<td>0.78–1.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never married</td>
<td>0.79</td>
<td>0.46–1.36</td>
<td>0.56</td>
<td>0.49–1.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonwhite vs. white</td>
<td>3.59</td>
<td>1.74–7.42</td>
<td>2.93</td>
<td>1.38–6.24</td>
<td>2.37</td>
<td>1.19–4.72</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>&lt;21</td>
<td>0.78</td>
<td>0.53–1.14</td>
<td>0.87</td>
<td>0.59–1.29</td>
<td>0.96</td>
<td>0.66–1.39</td>
</tr>
<tr>
<td>21–27</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
<td></td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>&gt;27</td>
<td>0.73</td>
<td>0.51–1.05</td>
<td>0.67</td>
<td>0.47–0.97</td>
<td>0.63</td>
<td>0.44–0.89</td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Never</td>
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<td>1.00</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Past</td>
<td>1.05</td>
<td>0.74–1.48</td>
<td>0.90</td>
<td>0.63–1.29</td>
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<tr>
<td>Current</td>
<td>1.55</td>
<td>0.97–2.46</td>
<td>1.04</td>
<td>0.63–1.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;12 years</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
<td></td>
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<tr>
<td>9–12 years</td>
<td>0.99</td>
<td>0.62–1.59</td>
<td>0.95</td>
<td>0.58–1.53</td>
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<td></td>
</tr>
<tr>
<td>≤8 years</td>
<td>0.83</td>
<td>0.53–1.31</td>
<td>0.65</td>
<td>0.59–1.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None in 1 year</td>
<td>0.80</td>
<td>0.57–1.12</td>
<td>0.81</td>
<td>0.57–1.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>None in 1 month</td>
<td>0.76</td>
<td>0.49–1.18</td>
<td>0.81</td>
<td>0.52–1.27</td>
<td></td>
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</tr>
<tr>
<td>&lt;1 ounce/day†</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>≥1 ounce/day</td>
<td>0.82</td>
<td>0.42–1.60</td>
<td>0.83</td>
<td>0.41–1.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity level</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>1.00</td>
<td></td>
<td>1.00</td>
<td></td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>1.31</td>
<td>0.90–1.90</td>
<td>1.20</td>
<td>0.82–1.76</td>
<td>1.25</td>
<td>0.87–1.82</td>
</tr>
<tr>
<td>High</td>
<td>2.04</td>
<td>1.36–3.07</td>
<td>1.75</td>
<td>1.14–2.66</td>
<td>1.86</td>
<td>1.24–2.79</td>
</tr>
<tr>
<td>Self-rated health (fair/poor vs. excellent/good)</td>
<td>0.78</td>
<td>0.58–1.06</td>
<td>0.69</td>
<td>0.51–0.94</td>
<td>0.67</td>
<td>0.50–0.89</td>
</tr>
<tr>
<td>Health conditions</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Cancer</td>
<td>1.49</td>
<td>1.01–2.20</td>
<td>1.37</td>
<td>0.92–2.04</td>
<td></td>
<td></td>
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<tr>
<td>Heart attack</td>
<td>1.25</td>
<td>0.85–1.83</td>
<td>1.17</td>
<td>0.79–1.73</td>
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<td></td>
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<tr>
<td>Angina</td>
<td>0.87</td>
<td>0.59–1.60</td>
<td>0.88</td>
<td>0.53–1.46</td>
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<td></td>
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<tr>
<td>Diabetes</td>
<td>0.86</td>
<td>0.57–1.30</td>
<td>0.77</td>
<td>0.50–1.17</td>
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<td></td>
</tr>
<tr>
<td>Stroke</td>
<td>0.50</td>
<td>0.29–0.89</td>
<td>0.51</td>
<td>0.29–0.92</td>
<td>0.49</td>
<td>0.28–0.86</td>
</tr>
<tr>
<td>High blood pressure</td>
<td>1.28</td>
<td>0.96–1.71</td>
<td>1.26</td>
<td>0.94–1.69</td>
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<tr>
<td>Hip fracture</td>
<td>1.03</td>
<td>0.55–1.93</td>
<td>1.09</td>
<td>0.57–2.08</td>
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<td></td>
</tr>
<tr>
<td>Arthritis</td>
<td>0.89</td>
<td>0.66–1.20</td>
<td>0.88</td>
<td>0.65–1.21</td>
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<td></td>
</tr>
<tr>
<td>Poor hearing</td>
<td>0.70</td>
<td>0.47–1.04</td>
<td>0.84</td>
<td>0.56–1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urinary incontinence</td>
<td>0.86</td>
<td>0.76–0.99</td>
<td>0.87</td>
<td>0.76–0.99</td>
<td>0.85</td>
<td>0.74–0.96</td>
</tr>
<tr>
<td>Poor vision</td>
<td>1.27</td>
<td>0.64–2.50</td>
<td>1.45</td>
<td>0.72–2.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg pain on walking</td>
<td>0.81</td>
<td>0.58–1.11</td>
<td>0.81</td>
<td>0.58–1.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shortness of breath</td>
<td>0.86</td>
<td>0.63–1.16</td>
<td>0.83</td>
<td>0.61–1.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Model 3 includes only significant predictors from model 2.
† OR, odds ratio; CI, confidence interval (from logistic regression); all models adjusted for EPESE site in addition to variables shown. An odds ratio >1.0 indicates greater likelihood of being nondisabled prior to death.
‡ One ounce = 30 ml.
TABLE 5. Likelihood of being nondisabled prior to death in very old age according to baseline physical activity level by strata of study site, sex, age at death, and baseline smoking status among decedents (n = 1,097) aged 80 years or older (men) and 85 years and older (women), Established Populations for Epidemiologic Studies of the Elderly (EPESE) cohorts, 1981-1991

<table>
<thead>
<tr>
<th>Strata</th>
<th>Physical activity level</th>
<th></th>
<th></th>
<th>Trend p value†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moderate vs. low</td>
<td>High vs. low</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adjusted OR*</td>
<td>95% CI*</td>
<td>Adjusted OR*</td>
<td>95% CI</td>
</tr>
<tr>
<td>EPESE site</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Boston, MA</td>
<td>1.05</td>
<td>0.56-1.99</td>
<td>2.12</td>
<td>0.99-4.55</td>
</tr>
<tr>
<td>Iowa</td>
<td>1.74</td>
<td>0.92-3.29</td>
<td>2.44</td>
<td>1.25-4.78</td>
</tr>
<tr>
<td>New Haven, CT</td>
<td>1.48</td>
<td>0.79-2.78</td>
<td>2.12</td>
<td>1.09-4.14</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>1.69</td>
<td>1.02-2.80</td>
<td>2.27</td>
<td>1.23-4.18</td>
</tr>
<tr>
<td>Men</td>
<td>1.13</td>
<td>0.67-1.92</td>
<td>1.90</td>
<td>1.10-3.26</td>
</tr>
<tr>
<td>Age at death (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;90</td>
<td>1.36</td>
<td>0.88-2.11</td>
<td>2.43</td>
<td>1.52-3.88</td>
</tr>
<tr>
<td>≥90</td>
<td>1.48</td>
<td>0.80-2.74</td>
<td>1.38</td>
<td>0.67-2.87</td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>1.55</td>
<td>0.96-2.49</td>
<td>2.36</td>
<td>1.40-4.00</td>
</tr>
<tr>
<td>Past</td>
<td>1.52</td>
<td>0.71-3.25</td>
<td>2.60</td>
<td>1.18-5.70</td>
</tr>
<tr>
<td>Current</td>
<td>1.08</td>
<td>0.42-2.77</td>
<td>1.18</td>
<td>0.39-3.54</td>
</tr>
</tbody>
</table>

* OR, odds ratio; CI, confidence interval (from logistic regression analysis); excluding the stratification variable, adjustment variables included EPESE site, age at death, and sex.
† Chi-square test for trend of three-level physical activity variable in separate adjusted models.

Physical activity may reduce disability in older persons through several mechanisms, including prevention of disease (20–22), reduction of the functional impact of existing disease, and slowing down or reversing functional and physiologic declines that result from aging and disuse. Promising new findings from a long-term randomized trial indicated that resistance or aerobic exercise can reduce disability and pain in older persons with arthritis, a major cause of disability in older adults (23). In addition, physical activity can reduce the risk of developing obesity, another major contributor to disability (24). Our own findings showed that heavier individuals were nearly 40 percent less likely than those in the mid-range of weight to die without activities of daily living disability. Accumulating evidence from randomized exercise trials and numerous observational studies suggests that physical activity may be a key strategy for preventing functional loss in older adults (25–27).

The measure of physical activity used in this study was limited to three types of activities, that is, walking, gardening, and vigorous exercise. Activity information was available for the entire cohort only at baseline, and we lacked information on history of physical activity. In spite of the limitations of the measure, we were able to detect a strong independent association between physical activity and disability prior to death. In the high activity category, the majority (56 percent) reported that they rarely or never did vigorous exercise; walking and gardening were their primary activities. In effect, persons with regular but moderate exercise were classified in the high activity category. It is an important finding that this moderate level of activity conferred protection from disability prior to death in very old age. Overall, 58 percent of study participants reported walking for exercise sometimes or frequently, consistent with other studies that reported walking to be the most common physical activity of older persons (28, 29). Our results are also consistent with research showing that walking for exercise prevents lower body disability and cardiovascular disease morbidity and mortality in older adults (8, 30).

Smokers were somewhat less likely to have disability in the year prior to death than past and never smokers (tables 2 and 3). However, any advantage in this regard was far outweighed when considering the overall probability of a smoker’s living to very old age, which at age 65 years was 63 percent that of nonsmokers. Even smokers who survived to very old age died younger than did nonsmokers. The logistic model adjusting for age at death (table 4, model 2) shows no difference between smokers and nonsmokers in the likelihood of dying without disability.

Heavier weight had a substantial negative impact on the likelihood of being free from activities of daily living disability prior to death in very old age. A higher
body mass index may contribute to increased risk of osteoarthritis (31) and cardiovascular disease (32) and has been found to be an independent risk factor for disability (8, 33, 34). Involuntary weight loss associated with ill health is common in very old adults, but the potential health benefits of voluntary weight reduction among very old adults is unclear. It is likely that reducing disease and disability risks related to overweight may require much earlier intervention in youth and middle age (35, 36).

The final follow-up interview for assessing disability prior to death occurred from 0 to 15 months prior to death. It could be argued that 15 months of disability prior to death is not insignificant and cannot be considered as "nondisability" prior to death. In fact, only a small proportion of decedents classified as nondisabled prior to death had their final interview 12–15 months prior to death (<14 percent). The average time to death following the final interview among our study subjects who were nondisabled prior to death was 8 months. Even if every one of these participants became disabled the day after the interview, this time interval until death is quite brief considering that persons aged 85 can typically expect to have on average more than 3 years of disability prior to death (37). In our study, the average time from the first report of disability to death among subjects classified as disabled prior to death was 32 months.

There are some limitations to the study that should be considered. Although the analysis was restricted to those who were not disabled in activities of daily living at baseline, persons who had some difficulties with activities of daily living or mobility were included. This could have resulted in an overestimation of the benefits of physical activity, since persons with functional difficulties would be less likely to participate in physical activity than their healthier counterparts. However, when the analysis was repeated using the smaller subset of persons who had no activities of daily living or mobility disability, the results were essentially the same, showing nearly a twofold benefit with higher levels of physical activity. Observational studies of exercise face the inescapable problem that unmeasured constitutional differences may exist between persons who are physically active and those who are not. When considering the beneficial effects of exercise in the prevention of coronary heart disease in the absence of large randomized trials, researchers and policy makers had to rely on evidence from large observational studies and small clinical studies of cardiovascular risk factors (25, 38). Findings from our study may eventually be confirmed through long-term randomized trials of exercise. Until that time, corroboration of our findings must come from further observational studies.

Second, by selecting only those who died after age 80 or 85 during follow-up, we may have reduced the representativeness of the study sample in comparison to the entire EPESE cohort. In order to be in the targeted age group for the 10-year follow-up, the men had to be age 70 or older and the women, age 75 or older, at baseline; thus, they were older than the original cohort. Those that died comprised a substantial proportion (37 percent) of those who were aged 80 (men) or 85 (women) prior to the end of the 8 years of follow-up. Assuming no major secular trends, we have no reason to believe that persons who died over the age of 80 in the first 8 years of follow-up would look markedly different before death than the EPESE survivors above age 80 or those who would subsequently age into the over-80 or over-85 group and die in the next 10 or more years. In addition, there is no reason to consider that the survivors' risk factors would have a different influence on their antemortem disability status than the findings on the 1,100 deaths in our analysis.

Another factor that could limit the representativeness of the study sample was the restriction based on follow-up time. Only persons who were in the study for 2 years were included, so that persons in unstable health or those whose health problems might have already led to changes in their behavioral risk factors at baseline were excluded. When we examined the proportions without disability prior to death in the entire cohort that died over age 80 (men) and 85 (women) (from the original 2,002 decedents on figure 1), we found that 46 percent of the men and 25 percent of the women were nondisabled prior to death. However, these proportions were not substantially different from the more restricted sample used in the analysis (49 percent of men and 30 percent of women died without disability). An additional concern is the low representation of racial minorities in the three EPESE sites. Future studies are needed to confirm whether the findings would be generalizable to blacks, Hispanics, and other racial groups.

Disability becomes more prevalent with age but, as demonstrated in this research, a substantial proportion of persons dying at advanced age do not have serious disability in the year before death. Furthermore, specific factors that predict both having a long life and dying without disability can be modified. These findings have the greatest implications for women aged 85 and older, half of whom need help with activities of daily living at home or are living in a nursing home. In our study, women who were the most physically active were more than twice as likely to be free of activities of daily living disability prior to death over the age of 85 compared with those who were inactive. However, fewer than 20 percent of the women studied were in the most physically active category at baseline, com-
pared with 40 percent of the men. Even a modest increase in the proportion of women who are physically active could potentially lead to tremendous savings, in terms of both health care costs and societal burden. However, it is crucial that these findings be confirmed in other study populations. This overview of factors associated with antemortem disability among the very old holds great promise that prolonged disability prior to death may not be an inevitable consequence of a long life and may be lessened or possibly prevented by modest changes in the level of physical activity.

ACKNOWLEDGMENTS

The authors thank Dr. Grant Izmirlian for his statistical consultation.

REFERENCES