Smoking, Physical Activity, and Active Life Expectancy

Luigi Ferrucci,1,2 Grant Izmirlian,2 Suzanne Leveille,2 Caroline L. Phillips,2 Maria-Chiara Corti,3 Dwight B. Brock,2 and Jack M. Guralnik2

The effect of smoking and physical activity on active and disabled life expectancy was estimated using data from the Established Populations for Epidemiologic Studies of the Elderly (EPESE). Population-based samples of persons aged >65 years from the East Boston, Massachusetts, New Haven, Connecticut, and Iowa sites of the EPESE were assessed at baseline between 1981 and 1983 and followed for mortality and disability over six annual follow-ups. A total of 8,604 persons without disability at baseline were classified as "ever" or "never" smokers and doing "low," "moderate," or "high" level physical activity. Active and disabled life expectancies were estimated using a Markov chain model. Compared with smokers, men and women nonsmokers survived 1.6–3.9 and 1.6–3.6 years longer, respectively, depending on level of physical activity. When smokers were disabled and close to death, most nonsmokers were still nondisabled. Physical activity, from low to moderate to high, was significantly associated with more years of life expectancy in both smokers (9.5, 10.5, 12.9 years in men and 11.1, 12.6, 15.3 years in women at age 65) and nonsmokers (11.0, 14.4, 16.2 years in men and 12.7, 16.2, 18.4 years in women at age 65). Higher physical activity was associated with fewer years of disability prior to death. These findings provide strong and explicit evidence that refraining from smoking and doing regular physical activity predict a long and healthy life.


activities of daily living; aging; exercise; longevity; longitudinal studies; Markov chains; motor activity; smoking

Smoking and sedentary lifestyle have been identified by McGinnis and Foege (1) as the first and second most important causes of death in the American population. Persons who do not smoke and are physically active not only enjoy greater longevity (2–5) but also have lower risk of developing myocardial infarction (6, 7), stroke (8, 9), cancer (10–12), respiratory diseases (12–14), and osteoporosis (15, 16). Since these pathologic conditions are major causes of severe disability in the older population (17), it may be hypothesized that persons who do not smoke and are physically active experience less disability in late life. Supporting this view, previous studies have found that older people who walk or are involved in other forms of regular exercise and those who do not smoke have a lower risk of losing mobility and developing disability (18–20).

Elucidating the relative magnitudes of the effects of smoking and physical activity on total survival and time of disability onset is important for understanding how these two risk factors influence the aging process. In persons with a beneficial risk factor profile, the delay in disability onset may be greater than the postponement of death, and therefore the number of years lived without disability may be greater, with a substantial improvement in the quality of life. At the other extreme, if longer life is not accompanied by a delay in the time of disability onset, the entire improvement in longevity could consist of years of disabled life. The true scenario, which probably lies between these two extremes, is presently unknown. In fact, no study, to our knowledge, has explicitly addressed this research question using data from a population sample including persons of very old age.

We used data from a large longitudinal study performed in a population-based sample of older persons to examine the joint effects of smoking and physical activity on active life expectancy and disabled life expectancy. We anticipated that persons who are physically active and nonsmokers tend to age successfully in that they not only live longer but also spend less time disabled at advanced ages than sedentary smokers.
MATERIALS AND METHODS

Sources of data

This study uses data from the Established Populations for Epidemiologic Studies of the Elderly (EPESE), a longitudinal study of persons aged 65 years and older, funded by the US National Institute on Aging (21). An in-person household survey was conducted between 1981 and 1983 on the entire elderly population living in East Boston (Massachusetts), in two Iowa counties, and on a probability sample stratified by sex and housing type of the New Haven (Connecticut) population. Follow-up data were collected annually in six follow-up interviews.

Autonomy, disability, and death

At baseline and each follow-up interview, participants were asked to report their ability to perform several basic activities of daily living, namely, walking across a small room, transferring from bed to chair, bathing, dressing, eating, grooming, and using the toilet (22). Self-report of need for help or inability to perform any of these activities was considered a state of disability. Complete data on mortality status over the entire follow-up period were collected primarily through linkage with the National Death Index, supplemented by obituaries and interviews with proxies.

Demographics, smoking, and physical exercise

Information on age, sex, smoking status, and level of physical exercise collected at baseline was used in this analysis. Smoking status was initially classified as current, past, or never smoker, based on responses to the two questions: “Do you smoke cigarettes regularly now?” and “Did you ever smoke cigarettes regularly?” However, after cross-classifying the study population according to community, sex, and physical activity, we found that the number of current smokers was too small in some of the cells and, therefore, in most analyses, we considered past and current smokers as a single group of ever smokers.

The level of physical activity was assessed by combining responses to questions concerning the activities of walking, gardening, and doing vigorous exercise (18). A score was assigned based on how often the participant typically performed an activity, using the following codes: 2 = several times per week; 1 = once a week or several times per month; and 0 = once a month or less. A composite score obtained by summing the three activity-specific scores was used to break the study population into three levels of physical activity: 0 = low (approximately first quartile), 1-2 = moderate (the two middle quartiles), and 3-6 = high (the upper quartile).

Study population

A total of 10,294 persons were interviewed at baseline. All baseline participants who reported disability (n = 1,323) or for whom disability status was unknown (n = 79) were excluded from the study population. This was done to remove the potential bias due to the fact that disability itself could have been the actual reason why some of the disabled participants were physically inactive. Participants who died (n = 288) or were lost to follow-up before the first annual interview were also excluded. The final study population consisted of 8,604 subjects.

Analysis

The expected survival time for a person of a given age (total life expectancy) was conceptualized as having two components: active life expectancy, defined as the expected number of years spent free from disability in the basic activities of daily living; and disabled life expectancy, defined as the expected number of years spent in a state of disability (23, 24). The probability of survival, development of disability, and recovery from disability during each 1-year time period between contiguous interviews of the EPESE was modeled as a Markov chain, which assumes that for each person the probabilities of transition between specific states are independent over successive years (25). In this model, age was treated as a time-dependent covariate and incremented by 1 year for each year of follow-up in the study. This analysis was performed using customized software designed to analyze stratified and complex sample survey situations (26) using the appropriate sandwich estimator of variance (27), allowing for missing data on disability status across follow-up interviews using the Markov assumption (28). The model was fitted on data collected from the first through the sixth annual follow-up interview. Information on smoking and the level of physical exercise used in the models was collected at baseline, when all persons in the study population were free of disability. The effect of each possible combination of sex, smoking status, and level of physical exercise was estimated independently by including 11 dummy variables as covariates in the model. However, since the direction and the magnitude of the effects were consistent across sexes, sex was considered as a main effect in the final analysis, and smoking and physical activity were cross-stratified.

From this analysis we obtained four sets of coefficients, each set estimating the effect of sex, smoking
status, and physical exercise on the age-specific probability of changing state over each 1-year period of follow-up from nondisability to death (P_{02}), disability to death (P_{12}), nondisability to disability (development of disability) (P_{01}), and disability to nondisability (recovery from disability) (P_{10}) (figure 1). The homogeneity of effects across EPESE sites was formally tested by comparing the coefficients and standard errors obtained by fitting the Markov model separately in the three cohorts.

The final transition probabilities were estimated on the entire EPESE population considered as a stratified probability sample while at the same time accounting for the complex sampling design of the New Haven cohort (21). The original sampling weights for New Haven were scaled so that their sum was equal to the total number of participants, while the East Boston and Iowa samples were considered as single strata, and a weight of 1 was assigned to each participant.

Smoothed single-year age- and sex-specific prevalences of disability were estimated from the population interviewed at the first annual follow-up, using logistic regression. Starting with these estimated prevalences of disability for each given age, transition rates derived from the Markov model were applied to project active life expectancy and disabled life expectancy for a hypothetical person of that age with a specific set of covariates, as the expected time spent in each state (29). Standard errors and confidence intervals for active life expectancy and disabled life expectancy were estimated using the delta method (30), and comparisons of active life expectancy and disabled life expectancy between subsets were performed using Student’s t tests. For the purpose of comparison, we also computed the expected length of disabled life for men and women in the study population conditioned on dying at specific ages, regardless of smoking and physical activity status.

The entire analysis was repeated after further restricting the study population to the 7,042 participants who at baseline reported being able to do heavy housework, walk half a mile, and walk up and down stairs to the second floor without help (31). Results were consistent with those of the previous analysis and are briefly summarized in the Results.

RESULTS

The main characteristics of the study population are reported in table 1, separately for the three sites of the EPESE. The East Boston population tended to be younger, while the distribution across sex was quite similar in the three samples. Smoking was less prevalent in Iowa, with only 8.8 percent current smokers at the time of the baseline interview, compared with 20.7 percent in both East Boston and New Haven. The large majority (83 percent) of the past smokers had quit smoking less than 5 years earlier, and almost all the current smokers (98.1 percent) had been smoking for more than 10 years.

The percentages of participants classified in the moderate and high level physical activity groups were, respectively, 64.3 percent and 20.2 percent in East Boston, 48.1 percent and 37.6 percent in Iowa, and 60.8 and 25.2 percent in New Haven.

Overall, smoking and level of physical activity were significantly lower in women compared with men (ever smoked: 26.5 percent vs. 65.7 percent, p < 0.001; high level physical activity: 23.2 percent vs. 35.8 percent, p < 0.001) and in participants aged 75 years and older compared with those 65–74 years of age (ever smoked: 32.5 percent vs. 47.8 percent, p < 0.001; high level physical activity: 22.4 percent vs. 31.8 percent, p < 0.001). There was no statistically significant difference in the distribution of smoking status across categories of physical activity. These findings were consistent across the three EPESE sites (table 1).

Several Markov models were fit to the data of the three EPESE sites to evaluate the effects of smoking and level of physical activity on the probability of changing state over a 1-year period. Transition probabilities calculated for men and women at age 70 years are shown in figure 2. Smoking was associated with a higher probability of dying for both disabled and nondisabled study participants, while the effect of smoking on new disability and recovery from disability was negligible and never statistically significant. In men and women, each increment in physical activity

[FIGURE 1. Possible changes of state over the 1 year between two consecutive interviews: transition to the death state in persons who did (P_{02}) and did not (P_{01}) report disability at the first of the two interviews, development of disability (P_{01}), and recovery from disability (P_{10}). Established Populations for Epidemiologic Studies of the Elderly (EPESE), 1981–1989. Note that a large proportion of participants remained in the same state.]

Am J Epidemiol Vol. 149, No. 7, 1999
TABLE 1. Study population according to age and sex, cross-classified by baseline smoking status and level of physical activity, for each of the three sites of the Established Populations for Epidemiologic Studies of the Elderly (EPESE), 1981–1983

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>65–74</th>
<th>75–84</th>
<th>&gt;85</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>1,178</td>
<td>1,257</td>
<td>2,058</td>
</tr>
<tr>
<td>Females</td>
<td>1,849</td>
<td>2,026</td>
<td>3,027</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Smoking* and physical activity</th>
<th>East Boston, MA (n = 3,027)</th>
<th>Iowa (n = 3,283)</th>
<th>New Haven, CT (n = 2,294)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never smoked</td>
<td>1,554 (51.3)</td>
<td>2,302 (70.1)</td>
<td>1,140 (49.7)</td>
</tr>
<tr>
<td>Low physical activity</td>
<td>257 (16.5†)</td>
<td>337 (14.6†)</td>
<td>161 (14.1†)</td>
</tr>
<tr>
<td>Moderate physical activity</td>
<td>1,018 (65.5†)</td>
<td>1,104 (48.0†)</td>
<td>689 (60.4†)</td>
</tr>
<tr>
<td>High physical activity</td>
<td>279 (18.0†)</td>
<td>861 (37.4†)</td>
<td>290 (25.4†)</td>
</tr>
<tr>
<td>Past smokers</td>
<td>847 (28.0)</td>
<td>682 (21.1)</td>
<td>679 (29.6)</td>
</tr>
<tr>
<td>Low physical activity</td>
<td>102 (12.0†)</td>
<td>90 (13.0†)</td>
<td>92 (12.1†)</td>
</tr>
<tr>
<td>Moderate physical activity</td>
<td>526 (62.1†)</td>
<td>326 (47.1†)</td>
<td>404 (59.5†)</td>
</tr>
<tr>
<td>High physical activity</td>
<td>219 (25.9†)</td>
<td>276 (39.9†)</td>
<td>193 (28.4†)</td>
</tr>
<tr>
<td>Current smokers</td>
<td>626 (20.7)</td>
<td>289 (8.8)</td>
<td>475 (20.7)</td>
</tr>
<tr>
<td>Low physical activity</td>
<td>111 (17.7†)</td>
<td>43 (14.9†)</td>
<td>78 (16.4†)</td>
</tr>
<tr>
<td>Moderate physical activity</td>
<td>402 (64.2†)</td>
<td>150 (51.9†)</td>
<td>302 (63.6†)</td>
</tr>
<tr>
<td>High physical activity</td>
<td>113 (18.1†)</td>
<td>96 (33.2†)</td>
<td>95 (20.0†)</td>
</tr>
</tbody>
</table>

* In subsequent analyses, past and current smokers were considered together in an "ever smoked" group.  † Percentage of those included in each specific smoking group.

was associated with a lower risk of dying in both nondisabled and disabled subjects, a substantially lower risk of new disability, and a higher probability of functional recovery. As expected, women had lower mortality and a slightly higher probability of becoming disabled.

Because all these findings were highly consistent across sites, all subsequent analyses were performed on the entire study population. The final Markov model included five dummy variables to estimate the effect of the six possible cross-combinations of smoking (two categories) and level of physical activity (three categories) with sex as a main effect. Using the coefficients produced by this model, we estimated age-specific active life expectancy and disabled life expectancy for men and women in each of these six groups.

Results are summarized in table 2. A 65-year-old man in the "ever smoked-low physical activity" category is expected to live 9.5 years of nondisabled life and 2 years of disabled life. A man of the same age but in the "never smoked-high physical activity" category is expected to live 16.2 years of nondisabled life and 2.5 years of disabled life. Differences according to smoking status are dramatic. In both men and women in the same category of physical activity, total life expectancy for smokers is almost always shorter than active life expectancy for nonsmokers. Since most disability occurs toward the end of life, this means that the average smoker will already be dead when nonsmokers are still nondisabled.

The effect of physical activity differs somewhat according to smoking status but is similar in men and women. Among never smokers, compared with participants in the low level group, those in the moderate level and those in the high physical activity groups have progressively longer active life expectancy. The magnitude of the increase in active life expectancy is substantial, 3.3 and 5.1 years in men and 3.5 and 5.7 years in women, respectively, and it is statistically significant for each incremental level of activity in both sexes. Since disabled life expectancy is not substantially different across levels of physical activity, the increase in active life expectancy with greater physical activity is mirrored by an increase in survival of the same magnitude (table 2).

Among men and women who ever smoked, there is also a substantial and significant increase in active life expectancy with increasing physical activity (table 2). A low level of physical activity is associated with greater disabled life expectancy than is moderate or high activity. However, those with moderate and low physical activity have similar total life expectancy.
FIGURE 2. Probability that a man or a woman 70 years old will die, become disabled, or recover from disability over the next year, according to his/her smoking status and level of physical activity at baseline, Established Populations for Epidemiologic Studies of the Elderly (EPESE), 1981–1989. Point estimates and 95% confidence intervals were obtained by fitting a Markov model, separately for the two sexes and each of the three EPESE cohorts.

TABLE 2. Active life expectancy (ALE) and disabled life expectancy (DLE) for men and women aged 65, according to smoking and level of physical activity, Established Populations for Epidemiologic Studies of the Elderly (EPESE), 1981–1989

<table>
<thead>
<tr>
<th></th>
<th>Smoked</th>
<th>Physical activity</th>
<th>Life expectancy (years)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>ALE Mean</td>
<td>95% Cl*</td>
<td>DLE Mean</td>
</tr>
<tr>
<td>Men</td>
<td>Never</td>
<td>High</td>
<td>16.2</td>
<td>15.2-17.2</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Never</td>
<td>Moderate</td>
<td>14.4</td>
<td>13.6-15.2</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Never</td>
<td>Low</td>
<td>11.1</td>
<td>10.3-12.0</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Ever†</td>
<td>High</td>
<td>12.9</td>
<td>12.0-13.8</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Ever†</td>
<td>Moderate</td>
<td>10.5</td>
<td>10.0-11.1</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Ever†</td>
<td>Low</td>
<td>9.5</td>
<td>8.7-10.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Women</td>
<td>Never</td>
<td>High</td>
<td>18.4</td>
<td>17.4-19.5</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>Never</td>
<td>Moderate</td>
<td>16.2</td>
<td>15.6-16.9</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>Never</td>
<td>Low</td>
<td>12.7</td>
<td>11.9-13.4</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>Ever†</td>
<td>High</td>
<td>15.3</td>
<td>14.3-16.4</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Ever†</td>
<td>Moderate</td>
<td>12.6</td>
<td>11.9-13.3</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Ever†</td>
<td>Low</td>
<td>11.1</td>
<td>10.2-11.9</td>
<td>3.1</td>
</tr>
</tbody>
</table>

* Cl, confidence interval.
† Includes both past and present smokers.

(active life expectancy + disabled life expectancy), but the moderate activity group has greater active life expectancy and shorter disabled life expectancy. An interesting comparison is between the "ever smoked-high physical activity" and the "never smoked- low physical activity" categories (table 2; fig-
In both men and women, the total survival in these groups is very similar, but disabled life expectancy is significantly shorter in smokers, suggesting that the level of physical activity is stronger than smoking as a predictor of the quality of life in old age.

Analyses performed in a subset of highly functioning participants who at baseline reported being able to do heavy housework, walk half a mile, and walk up and down stairs to the second floor without help yielded results consistent with those shown in table 2. On average, smoking accounted for 3.2 less years of active life expectancy. Differences in active life expectancy between a low and a high level physical activity were greater in nonsmokers (4.1 years in men and 3.7 years in women) than in smokers (2.6 years in men and 2.3 years in women), and they were statistically significant within every sex-smoking subgroup (data not shown).

Estimates for active life expectancy and disabled life expectancy for men and women according to smoking and physical activity were also calculated for age 75. In figure 3, these values are compared with those estimated for men and women aged 65 years. It is quite evident that active life expectancy decreases with age while disabled life expectancy tends to represent a larger percentage of the total life expectancy. The difference in total life expectancy according to smoking status is still statistically significant at age 75. However, in both men and women, while the effect of physical activity on active life expectancy is still detectable after age 80, because of the extreme contraction of active life expectancy and reduced sample size, the difference is no longer statistically significant (data not shown).

To better understand the results shown in table 2, one should consider that, as a general trend, persons who die later tend also to experience longer disabled life expectancy. However, average disabled life expectancy associated with a specific age at death and sex may be different in subsets of the population defined by particular risk factor profiles. To address this issue, we estimated the time spent in a state of disability by average men and women (regardless of their level of physical exercise and smoking status) who...
were assumed to die at ages that correspond exactly to the expected age at death of the 12 subgroups described in table 2. Note that, compared with the previous analysis, here we estimated disabled life expectancy considering age at death as a fixed reference point. The results are shown in table 3.

Men 65 years old who never smoked and are in the high, moderate, and low physical activity groups have approximately 2.6 years of disabled life expectancy and are expected to die, respectively, at ages 83.7, 82.0, and 78.7 years (table 3). The corresponding expected lengths of disabled life for the average men in the study population who are assumed to die at exactly these three ages are 3.0, 2.4, and 1.4 years. Thus, the high physical activity group spends less time disabled than the overall population of men who die at the same age (2.5 vs. 3.0 years), while the low physical activity group actually spends more time disabled than all men who die at the same age (2.6 vs. 1.4 years). These comparisons suggest that physical activity reduces the burden and duration of disability that often precede death, a phenomenon analogous to what has been defined as “compression of morbidity.” The effect of “compression” holds in men and women and in smokers and nonsmokers.

### TABLE 3. Disabled life expectancy (DLE) and expected age at death (age T) estimated for men and women aged 65 years, according to smoking status and level of physical activity, Established Populations for Epidemiologic Studies of the Elderly (EPESE), 1981–1989

<table>
<thead>
<tr>
<th>Sex</th>
<th>Smoked</th>
<th>Physical activity</th>
<th>DLE at age 65 (years)</th>
<th>Expected age (years) at death for the group (age T)</th>
<th>Expected length of disabled life (years) for average men and women dying at exactly age T*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>Never</td>
<td>High</td>
<td>2.5</td>
<td>83.7</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>2.6</td>
<td>82.0</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>2.6</td>
<td>76.7</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Ever†</td>
<td>High</td>
<td>1.3</td>
<td>79.2</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>1.3</td>
<td>76.8</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>2.0</td>
<td>76.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Women</td>
<td>Never</td>
<td>High</td>
<td>3.6</td>
<td>87.2</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>3.9</td>
<td>85.1</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>3.8</td>
<td>81.5</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>Ever†</td>
<td>High</td>
<td>2.2</td>
<td>82.5</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>2.2</td>
<td>79.8</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>3.1</td>
<td>79.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>

* The last column reports, for comparison, the expected number of years spent in a state of disability by men and women in the whole study population (regardless of physical activity and smoking status) who are assumed to die exactly at age T.
† Includes both past and present smokers.

**DISCUSSION**

Using data from a longitudinal survey of a population-based sample of older persons followed annually for 6 years, this study provides strong and explicit evidence that nonsmoking and regular physical activity are powerful predictors of a long and healthy life.

There is extensive and longstanding evidence showing that smoking and physical activity have, respectively, substantial negative and positive effects on health. At the beginning of this century, an English physician observed that 90 percent of his patients who complained of intermittent claudication were smokers (32). The first paper providing scientific evidence that smoking was associated with premature mortality was published in *Science* in 1939 (33). A positive effect of physical activity on heart disease and all-cause mortality was reported as early as 1939 (34), although positive effects on health had already been mentioned in ancient Chinese and Greek documents (35). Over the past 50 years, a considerable number of surveys conducted in different parts of the world have consistently reported that, independent of other risk factors, individuals who do not smoke and who are physically active are more likely to enjoy longevity (2–5) and less likely to develop many of the chronic conditions that are highly prevalent in the older population (6–16). Studies have also identified plausible biologic mechanisms that may explain these associations (36, 37).

By quantifying the effect of these factors on total and disability-free life expectancy, our study presents a global picture of how smoking and physical activity together influence longevity and the quality of aging. Because of the overwhelming evidence that smoking and level of physical activity predict morbidity and mortality, the fact that they were found to be associated with active life expectancy was not surprising. However, the magnitude of these effects was very striking.

Differences in total life expectancy from age 65 between smokers and nonsmokers were as large as 5 years. Compared with physical inactivity, moderate to high level physical activity was associated, on average, with 3 or more additional years of expected life. This longer survival was completely attributable to longer active life expectancy, without any substantial differences in disabled life expectancy. These data should be interpreted keeping in mind that, on average, persons who die older tend also to experience more disability prior to death (table 3) (38). To the best of our knowledge, this is the first study showing that physical activity in the older population prolongs active life, decreases the percentage of remaining life that is spent in the state of disability, and, compared with people who die at the same age in the general population, is associated with a shorter period of disability. Thus,
physical exercise is the ideal candidate for a community-based intervention in the older population.

In agreement with existing literature (19, 39), in a comparison with those with low physical activity, this study found that moderate physical activity in smokers had no beneficial effect on survival (tables 2 and 3). However, even moderate physical activity was associated with a significant delay in the onset of disability and therefore may have a positive influence on the quality of life in old age. Indeed, the results of our analyses suggest that the negative effect of inactivity on survival and length of disabled life is comparable and perhaps higher than the effect of smoking. These results are consistent with data showing that the magnitude of the relative risks of developing an acute coronary event associated with inactivity and smoking is substantially similar and comparable to the excess of risk conferred by other major risk factors, such as hypertension and high cholesterol levels (40).

In addition to the fact that our findings are based on one of the largest population-based studies of older persons, with annual follow-up visits over a 6-year period, a major strength of this research is the new analytical method that was used to estimate active and disabled life expectancy, which overcomes some of the limitations of previous techniques (23, 24). Instead of using a single follow-up, we estimated probabilities of transition between different states using information collected over multiple follow-up interviews, therefore obtaining more precise estimates. The method allows for missing data on disability status and takes into account complex sampling designs. Finally, using this method we could estimate confidence intervals for active life expectancy and disabled life expectancy, allowing for the formal statistical comparison of different groups.

Three potential limitations of our analysis should be considered. First, since it is likely that some of the disabled persons could not be physically active because of their disability, we excluded from the study population all persons who reported disability at baseline. However, as in any other observational study of physical activity, in certain subjects in our study population, a low activity level could still be a marker of poorer health status and therefore predict negative health-related outcomes. The fact that the results were essentially unchanged after further restricting the study population to a highly functional subgroup indicates that this limitation had a relatively small impact.

Second, because of small sample sizes, we were unable to tease out the separate effects of current and past smoking. Changes in smoking behavior over the follow-up were reported by less than 5 percent of the smokers and none of the nonsmokers, a too small percentage to perform a meaningful analysis. It may be hypothesized that the beneficial effect of quitting smoking on multiple outcomes, shown by many different studies (3, 41), will translate into improvements in total and active life expectancy. However, this hypothesis needs to be tested in further studies.

Finally, given the observational nature of this study, extrapolations of the possible effects of changing smoking behavior and level of physical activity in late life require caution. For example, positive effects of physical activity have been demonstrated for intermediate predictors of morbidity and mortality such as blood pressure (42), lipid profile (43), and glucose tolerance (44). Unfortunately, no data from large clinical trials looking at mortality and incident disability related to smoking and exercise behavior are currently available, and the feasibility of such a trial is questionable (45).

Even with these limitations, this study presents a powerful picture of the joint influence of smoking and physical exercise on longevity and the quality of aging. These findings have considerable individual and public health implications. For a man or woman who decides to start exercising, being aware of how many years of total and "good" life he or she may be gaining could be a powerful incentive toward the healthy choice. From a population perspective, health care planners need to project how complex changes in health behaviors may affect future health care expenditures. For example, when estimating the effect of reducing smoking, these planners should take into account that quitting smoking is often part of a more global change in lifestyle that includes increasing physical activity and improving other health-related behaviors. The overall effect of these changes may be substantially better than the effect expected from quitting smoking alone.

Only a small proportion of older persons living in the United States and Europe are regularly involved in physical activities (46), and worldwide almost 4 million persons die every year from diseases that are directly attributable to smoking (47). No other interventions, except perhaps reducing social inequalities, have more potential for improving life in old age than preventing or stopping smoking and promoting physical activity. Lifetime benefits will accrue through interventions over the entire age spectrum, in children as well as in the oldest old population. Resources allocated for this purpose could turn out to be the most cost-effective investment in health care in our time.

ACKNOWLEDGMENTS

This study was completed when Dr. Ferrucci and Dr. Corti were Visiting Scientists at the National Institute on Aging.
REFERENCES