Physical Activity at Midlife in Relation to Successful Survival in Women at Age 70 Years or Older

Qi Sun, MD, ScD; Mary K. Townsend, ScD; Olivia I. Okereke, MD; Oscar H. Franco, MD, ScD, PhD; Frank B. Hu, MD, PhD; Francine Grodstein, ScD

Background: Physical activity is associated with reduced risks of chronic diseases and premature death. Whether physical activity is also associated with improved overall health among those who survive to older ages is unclear.

Methods: A total of 13,535 Nurses’ Health Study participants who were free of major chronic diseases at baseline in 1986 and had survived to age 70 years or older as of the 1995-2001 period made up the study population. We defined successful survival as no history of 10 major chronic diseases or coronary artery bypass graft surgery and no cognitive impairment, physical impairment, or mental health limitations.

Results: After multivariate adjustment for covariates, higher physical activity levels at midlife, as measured by metabolic-equivalent tasks, were significantly associated with better odds of successful survival. Significant increases in successful survival were observed beginning at the third quintile of activity: odds ratios (ORs) (95% confidence intervals [CIs]) in the lowest to highest quintiles were 1 [Reference], 0.98 (0.80-1.20), 1.37 (1.13-1.65), 1.34 (1.11-1.61), and 1.99 (1.66-2.38) (P < .001 for trend). Increasing energy expenditure from walking was associated with a similar elevation in odds of successful survival: the ORs (95% CIs) of successful survival across quintiles of walking were 1 [Reference], 0.99 (0.80-1.21), 1.19 (0.97-1.45), 1.50 (1.24-1.82), and 1.47 (1.22-1.79) (P < .001 for trend).

Conclusion: These data provide evidence that higher levels of midlife physical activity are associated with exceptional health status among women who survive to older ages and corroborate the potential role of physical activity in improving overall health.

Arch Intern Med. 2010;170(2):194-201

The past century has witnessed a dramatic increase in life expectancy in the United States, from 47.3 years in 1900 to 75.2 years for men and 80.4 years for women in 2005. Together with a decreased birth rate and the aging of baby boomers, it is projected that by 2030, 1 in every 5 Americans will be 65 years or older. Older adults are disproportionately affected by chronic diseases and functional disabilities, and the attendant medical and social costs are tremendous. However, development of chronic diseases and disabilities is not inevitable among aged populations. Several studies have demonstrated that as many as 10% to 50% of those 65 years or older can maintain physical and cognitive integrity and remain free of major chronic illnesses. Indeed, limited epidemiologic studies conducted primarily among older male populations have identified several modifiable midlife risk factors, such as smoking and obesity, associated with the probability of exceptional health among those who survive to older ages. Furthermore, physical activity is a well-established approach to reducing risks of many chronic diseases, and potentially other aspects of health. However, findings from limited existing studies of the relation between midlife physical activity and overall health and well-being at older ages have been inconsistent. For example, several studies among men and women found that physical activity increased healthy aging, disability-free survival, or self-reported physical and overall health, while a more recent study of Japanese American men reported a null association with successful survival. Moreover, evidence specifically among women is lacking, despite the fact that women live longer than men; thus, identifying risk fac-

See also pages 124, 170, 179, and 186
tors for successful survival is particularly important among women. Finally, limited research has addressed the dose-response relationship and intensity of activities in relation to successful survival.

Herein, we use data from the Nurses’ Health Study (NHS) to further explore the relation between midlife physical activity, including walking, and successful aging as measured by a full spectrum of health outcomes, including incidence of chronic diseases, cognitive and physical functioning, and mental status.

METHODS

STUDY POPULATION

The NHS is an ongoing prospective cohort study initially comprising 121 700 female registered nurses, aged 30 to 55 years, who responded to a baseline questionnaire in 1976. Follow-up questionnaires have been administered to the participants every 2 years since 1976 to collect and update the information on incidence of diseases and demographic and lifestyle risk factors. In 1986, we started collecting detailed information on physical activity. Through 2000, the close of follow-up for most participants in the present analyses, the follow-up rate was greater than 95%.

ASSESSMENT OF PHYSICAL ACTIVITY

In 1986, we inquired about the average time per week in the past year participants spent on leisure-time physical activities, including walking or hiking outdoors; jogging ($\geq 10 \text{ min/mile}$); running ($< 10 \text{ min/mile}$); bicycling; lap swimming; playing tennis; doing calisthenics, aerobics, aerobic dance, and/or rowing machine exercise; and playing squash or racquet ball. For each question, there were 10 possible response categories (range, 0 to $\geq 11 \text{ h/wk}$). Furthermore, we inquired about flights of stairs climbed each day, and, for walkers, the usual walking pace: easy or casual ($< 2.0 \text{ mph}$), normal (2.0-2.9 mph), brisk (3.0-3.9 mph), and very brisk ($\geq 4.0 \text{ mph}$). Based on this information, we calculated energy expenditure in metabolic-equivalent tasks (METs) measured in hours per week. Each MET-hour is the caloric need per kilogram of body weight per hour of activity divided by the caloric need per kilogram of weight per hour at rest. According to this standard, we assigned a MET value of 1.2 to running; 8.0 to stair-climbing; 7.0 to jogging, bicycling, lap swimming, and playing tennis and other racquet sports; 6.0 to aerobics and calisthenics; and 2.5 to 4.5 to walking, depending on the pace. In other words, for example, running for an hour would generate 12 METs’ energy expenditure; climbing stairs for an hour would generate 8 METs’ energy expenditure, and so on. The same amount of energy expenditure can be achieved by various physical activities. For example, to achieve 30 METs/wk, a woman can run for 2.5 h/wk or swim for 4.3 h/wk. In analyses of activity intensity, we defined activity with a MET value larger than 6 as vigorous; walking was defined as a moderate-intensity activity owing to the lower MET value.

For the current analysis, we used 1986, when detailed physical activity information was first obtained, as the study baseline. Moreover, in all analyses, we only considered physical activity reported in 1986 because we wanted to minimize the possibility of reverse causation with aging (ie, if poor underlying health status caused decreased physical activity rather than the opposite). At baseline in 1986, the mean age was 60 years for our study participants, and therefore, midlife was defined as age 60 years for the purposes of this report.

The physical activity questionnaire has been validated in a similar population (the NHS II). In a representative sample of 147 nurses, the physical activity scores based on this questionnaire administered 2 years apart were reasonably correlated, given some true changes in activity across 2 years; the test-retest correlation coefficient ($r$) was 0.59. The questionnaire estimate of physical activity levels was highly correlated with those reported in 1-week recalls ($r=0.79$) and those logged in diaries during the year ($r=0.62$).

ASSESSMENT OF CHRONIC DISEASES

A wide variety of major chronic diseases (ie, cancer, diabetes, coronary heart disease, stroke, Parkinson disease, and multiple sclerosis) were reported by participants in 1976 and in biennial follow-up questionnaires. The self-reports were confirmed by study physicians through a variety of methods, such as medical record review, pathology report review, telephone interview, or supplementary questionnaire inquiries. The self-report of incidence of chronic diseases among these nurses has been previously demonstrated to be highly valid.

ASSESSMENT OF PHYSICAL FUNCTION AND MENTAL HEALTH

In 1992, 1996, and 2000, we added the Medical Outcomes Survey Short-Form Health Survey (SF-36) to the follow-up questionnaires to assess the physical and mental status of the participants. The SF-36 is a 36-item questionnaire that measures eight health concepts, including limitations of physical activities, usual role activities, social activities, mental health, bodily pain, vitality, and general health perceptions. The validity and reproducibility of the SF-36 have been extensively examined and reported elsewhere.

ASSESSMENT OF COGNITIVE FUNCTION

From 1995 to 2001, we invited all nurses 70 years or older who were free of stroke to participate in a cognitive function study. Of 21 202 invited nurses, 19 415 (92%) agreed to participate and were administered the Telephone Interview for Cognitive Status (TICS), which is modeled on the Mini-Mental State Examination. Scores on the TICS have a range of 0 (worst) to 41 (perfect), with a score lower than 31 indicating cognitive impairment. The high test-retest reliability and validity of TICS compared with in-person cognitive testing have been demonstrated previously. Trained study nurses who were unaware of the study hypothesis and exposure status of the participants administered the TICS with high inter-interviewer reliability. Owing to the availability of cognitive data from this group, the present analysis was conducted among these participants.

DEFINITION AND ASCERTAINMENT OF SUCCESSFUL AGING

To evaluate the overall health status of the study participants, we used the concept of successful aging first outlined by Rowe and Kahn, which takes into account both comorbidities and disabilities. The working definition of successful aging has been introduced in detail elsewhere. Briefly, our definition of successful aging addressed 4 domains: (1) no history of cancer (except nonmelanoma skin cancer), diabetes, myocardial infarction, coronary artery bypass graft surgery (CABG), congestive heart failure, stroke, kidney failure, chronic obstructive pulmonary disease, Parkinson disease, multiple sclerosis, or amyotrophic lateral sclerosis; (2) no impairment in cognitive function (TICS score $\geq 31$); (3) no physical disabilities (no limitations on...
moderate activities and no more than moderate limitations on
demanding physical performance measures); and (4) no
mental health limitations (mental health score >84, which is the
median score in our study population). Any participant who sur-
vived to at least age 70 years and met all these criteria was de-
fined as a successful survivor; the remaining participants who sur-
vived to at least aged 70 years but had a chronic disease history,
CABG, cognitive impairment, physical or mental health limita-
tions were defined as usual survivors. Since the cognitive func-
tion of most study participants was assessed in the 1990-2000
period (87.5%), we used the year 2000 to define chronic dis-
ease status. Similarly, physical and mental health domains were
primarily derived from the SF-36 administered in 2000.

We excluded nurses who had a history of any of the re-
levant chronic diseases or CABG at baseline (n=2361) or who
had missing physical activity data at baseline (n=2724). We
further excluded those who skipped more than 2 items on the
mental health scale at 70 years or older or more than 5 items
on the physical function scale in the SF-36 (n=795). After these
participants were excluded, data from 13 353 nurses were avail-
able for analysis. All participants gave informed consent. The
study protocol was approved by the institutional review board
of the Brigham and Women's Hospital.

STATISTICAL ANALYSIS

We grouped the study participants into quintiles of total METs.
We used logistic regression to assess the odds ratios (ORs) of
successful survival vs usual survival associated with each quint-
tile, defining the lowest quintile as the reference level. In mul-
tivariate logistic regression models, we adjusted for variables
defined in 1986, including age at baseline (in years); educa-
tion (registered nurse, bachelor's degree, master's degree, or
doctorate); marital status (unmarried, married, widow, separated,
or divorced); if married, husband's education (less than high
school, some high school, high school graduate, college gradu-
ate, or graduate school); postmenopausal hormone use (never,
past, or current use); smoking status (never, past, current 1-14
cigarettes/d, current 15-24 cigarettes/d, or current ≥25 cigarettes/
d); family history of heart disease, diabetes, or cancer (yes or
no); dietary polyunsaturated to saturated fat ratio (in quin-
tiles); intakes of trans fat, alcohol, and cereal fiber (all in quin-
tiles); and intakes of fruits and vegetables and red meat (in ter-
tiles). Since moderate-intensity physical activity such as walking
was associated with lower risk of chronic diseases in previous
studies by our research group, we further examined walk-
ing METs and pace in relation to successful survival in the
present study. When examining the associations for walking
MET quintiles, we further adjusted for vigorous activity METs
to minimize potential confounding by vigorous physical activ-
sity. Similarly, when we examined the associations for walking
pace, we further controlled for total METs.

Tests of linear trend across increasing MET quintiles were
conducted by treating the quintiles as a continuous variable and
assigning the median score for each quintile as its value. All P
values were 2 sided. Ninety-five percent confidence intervals
(95% CIs) were calculated for ORs. Data were analyzed with
the Statistical Analysis Systems software package, version 9.1

SENSITIVITY ANALYSES

We performed 3 secondary sensitivity analyses to examine the
robustness of observed associations. First, although we ex-
cluded anyone with major chronic diseases at baseline, and im-
posed an average 14-year lag period between the assessment
of activity levels and the assessment of successful survival, it is
still possible that long-term physical disabilities at baseline might
have biased our analysis. To address this issue, rather than com-
pare women with the least and the most activity, we repeated
the analysis only within participants who reported having at
least a minimum level of activity, which we defined as walk-
ing at least 1 hour per week or performing any vigorous activ-
ity at least 20 minutes per week at baseline. Second, to best ad-
dress the independent effects of walking as exercise, we estimated
the ORs associated with walking METs after excluding women
who both walked and participated in vigorous activity. Fi-
nally, to examine the robustness of our definition of suc-
cessful aging, we repeated the analysis using an alternative defi-
nition that included the same criteria for chronic disease status,
but used median score to define the cut points for cognitive,
physical, and mental health domains. We conducted this analy-
sis because, while the domains we used for considering suc-
cessful survival are widely accepted, the specific criteria for de-
fining “successful” within each domain is less established.

RESULTS

Of the total of 13 353 participants, 1456 (10.8%) met the
criteria for successful survivor. Table 1 summarizes the
baseline characteristics of the participants in 1986. As ex-
pected, successful survivors were more active than usual
survivors. The successful survivors were also leaner and
less likely to smoke than usual survivors and had a slightly
lower prevalence of hypertension or high cholesterol levels.

Table 2 summarizes the age- and multivariate-
adjusted ORs of successful survival associated with quin-
tiles of total physical activity METs and walking METs.
After adjustment for multiple covariates, the ORs for suc-
cessful survival across quintiles were 1 [reference], 0.98,
1.37, 1.34, and 1.99 for total METs (P<.001 for trend).
We also found associations of similar strength between
walking METs and the odds of successful aging. After mul-
tivariate adjustment of covariates, ORs for successful sur-
 vivor across walking METs quintiles were 1 [reference],
0.99, 1.19, 1.50, and 1.47 (P<.001 for trend). Further
adjustment for possible intermediate variables, such as
 body mass index (BMI), history of hypertension, and
history of hypercholesterolemia, did not change these as-
sociations materially.

Independent of the total physical activity levels, in-
creasing walking pace was also strongly associated with
a significant increase in odds of successful aging (Table 3).
Compared with women whose walking pace was easy, women
with a moderate walking pace had a 90% increase in the odds of successful aging; women
whose walking pace was brisk or very brisk had 2.68-
fold increased odds. To help disentangle the effects of the
amount walked on the association with walking pace, we
stratified the analysis by lower or higher levels of walk-
ing METs. Walking pace was similarly associated with
increased odds of successful aging for both groups.

Acknowledging the interrelationship between BMI and
physical activity, we also examined the joint associations
of BMI in 1986 and total physical activity with successful
survival (Figure). The positive associations between physi-
cal activity and successful aging persisted within each BMI
category (calculated as weight in kilograms divided by height

(Continued on next page)
in meters squared). Nonetheless, women who were both lean (BMI, 18.5-22.9) and active (highest tertile of total METs) had the highest odds of successful survival in comparison with women who were overweight (BMI, ≥25) and sedentary (bottom tertile of total METs): the OR was 3.44 (95% CI, 2.74-4.31).

We also considered specific types of vigorous activities. After controlling for moderate-intensity activity METs, we found that several individual vigorous activities were each associated with significantly elevated odds of successful aging. The multivariate ORs (95% CIs) comparing any vs none were 1.66 (1.30-2.14) for jogging, 1.87 (1.33-2.61) for running, 1.34 (1.03-1.74) for playing tennis, and 1.23 (1.09-1.39) for doing aerobics or calisthenics.

**SECONDARY ANALYSIS**

We observed similar associations for total METs when we restricted our analysis to women who were capable of performing at least low- to moderate-intensity activi-

---

**Table 1. Baseline Characteristics of Successful Survivors and Usual Survivors in the Nurses’ Health Study**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Successful Survivors</th>
<th>Usual Survivors</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n=1456)</td>
<td>(n=12 079)</td>
<td></td>
</tr>
<tr>
<td>Age at baseline, y</td>
<td>60.1 (2.5)</td>
<td>60.6 (2.5)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Age at cognitive function assessment, y</td>
<td>73.7 (2.1)</td>
<td>74.2 (2.3)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Physical activity, METs (h/wk)</td>
<td>19.1 (22.0)</td>
<td>14.1 (19.7)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Walking activity, METs (h/wk)</td>
<td>9.5 (11.5)</td>
<td>7.2 (9.7)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>BMI</td>
<td>23.8 (3.3)</td>
<td>25.5 (4.4)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Waist circumference, cm</td>
<td>76.2 (8.2)</td>
<td>80.6 (10.3)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Waist to hip ratio</td>
<td>0.78 (0.08)</td>
<td>0.79 (0.07)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Saturated fat intake, g/d</td>
<td>12.5 (2.5)</td>
<td>12.9 (2.4)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Polyunsaturated fat intake, g/d</td>
<td>5.8 (1.3)</td>
<td>5.9 (1.3)</td>
<td>.003</td>
</tr>
<tr>
<td>Polysaturated to saturated fat ratio</td>
<td>0.50 (0.15)</td>
<td>0.50 (0.14)</td>
<td>.07</td>
</tr>
<tr>
<td>trans Fat intake, g/d</td>
<td>1.8 (0.6)</td>
<td>1.9 (0.5)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Alcohol intake, g/d</td>
<td>7.1 (9.9)</td>
<td>6.7 (9.9)</td>
<td>.15</td>
</tr>
<tr>
<td>Cereal fiber intake, g/d</td>
<td>4.2 (2.1)</td>
<td>4.0 (2.0)</td>
<td>.004</td>
</tr>
<tr>
<td>Red meat intake, serving/d</td>
<td>1.0 (0.5)</td>
<td>1.1 (0.5)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Fruits and vegetables, serving/d</td>
<td>5.4 (2.0)</td>
<td>5.2 (2.0)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Smoking status c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoked</td>
<td>53.5</td>
<td>46.4</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Past smoker</td>
<td>34.8</td>
<td>36.2</td>
<td></td>
</tr>
<tr>
<td>Current smoker, 1-14 cigarettes/d</td>
<td>5.7</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>Current smoker, 15-24 cigarettes/d</td>
<td>4.3</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Current smoker, ≥25 cigarettes/d</td>
<td>1.7</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Registered nurse</td>
<td>74.0</td>
<td>79.0</td>
<td></td>
</tr>
<tr>
<td>Bachelor’s degree</td>
<td>17.3</td>
<td>14.9</td>
<td></td>
</tr>
<tr>
<td>Master’s degree</td>
<td>8.0</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>Doctorate</td>
<td>0.7</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Husband’s education c</td>
<td></td>
<td></td>
<td>.01</td>
</tr>
<tr>
<td>Less than high school</td>
<td>2.2</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Some high school</td>
<td>5.4</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>High school graduate</td>
<td>39.4</td>
<td>42.9</td>
<td></td>
</tr>
<tr>
<td>College graduate</td>
<td>28.7</td>
<td>27.6</td>
<td></td>
</tr>
<tr>
<td>Graduate school</td>
<td>24.2</td>
<td>20.5</td>
<td></td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td></td>
<td>.47</td>
</tr>
<tr>
<td>Married</td>
<td>63.2</td>
<td>62.2</td>
<td></td>
</tr>
<tr>
<td>Widowed</td>
<td>33.2</td>
<td>34.6</td>
<td></td>
</tr>
<tr>
<td>Separated, divorced, or never married</td>
<td>3.6</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>PMH status c</td>
<td></td>
<td></td>
<td>.01</td>
</tr>
<tr>
<td>Never used</td>
<td>34.1</td>
<td>31.0</td>
<td></td>
</tr>
<tr>
<td>Current user</td>
<td>36.9</td>
<td>36.7</td>
<td></td>
</tr>
<tr>
<td>Past user</td>
<td>29.0</td>
<td>32.4</td>
<td></td>
</tr>
<tr>
<td>Family history</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart disease</td>
<td>15.0</td>
<td>17.7</td>
<td>.01</td>
</tr>
<tr>
<td>Diabetes</td>
<td>26.7</td>
<td>29.7</td>
<td>.01</td>
</tr>
<tr>
<td>Cancer</td>
<td>16.7</td>
<td>18.3</td>
<td>.14</td>
</tr>
<tr>
<td>History of hypertension</td>
<td>21.5</td>
<td>33.5</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>History of high cholesterol</td>
<td>12.2</td>
<td>17.8</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

**Abbreviations:** BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); METs, metabolic-equivalent tasks (measured in hours per week; each MET-hour is the caloric need per kilogram of body weight per hour of activity divided by the caloric need per kilogram of weight per hour at rest); PMH, postmenopausal hormone use.

Data are reported as means (SDs) for continuous variables or percentages for categorical variables.

P values are based on the t test for continuous variables or χ² test for categorical variables.

Proportions are based on nonmissing values.
ties at baseline: the ORs (95% CIs) across total METs quintiles were 1 [reference], 1.53 (1.20-1.95), 1.38 (1.08-1.77), 1.83 (1.44-2.32), and 2.04 (1.61-2.58) (P < .001 for trend). Likewise, associations for walking METs were largely unchanged when we repeated the analysis among women who did not engage in any vigorous activity: the ORs (95% CIs) were 1.32 (1.03-1.69) for women in the middle tertile and 1.64 (1.32-2.04) for women in the highest tertile of walking METs.

Finally, of 13,535 participants, 1252 (9.3%) met the criteria of the alternate successful survival definition. In analyses of physical activity and this alternate definition, we found similar associations. For example, the ORs (95% CIs) for total activity METs quintiles were 1 [reference], 1.27 (1.02-1.57), 1.49 (1.22-1.83), 1.63 (1.33-2.00), and 1.93 (1.38-2.36), indicating that our results were robust to different definitions of successful survival (P < .001 for trend).

### COMMENT

In this large study of women, we documented a strong, positive association between midlife leisure-time physical activity and the odds of successful survival or exceptional overall health in later life. This included a positive relation between moderate-intensity activity, such as walking, and odds of maintaining overall health status among aging women.

There is persuasive evidence supporting an inverse association between physical activity and many individual aspects of health, including multiple chronic diseases, cognitive function, physical function, and mental health. However, fewer epidemiologic studies have examined the association of physical activity with overall health status as evaluated by multiple domains among those who have survived to older ages. In addition, existing data are primarily for men and women, for whom physical activity patterns tend to be different from those of men. Nonetheless, similar to the Cardiovascular Health Study participants and male Harvard college alumni, midlife physical activity was associated with an improved overall health status at older ages. In contrast, among male Japanese Americans, midlife physical activity was not associated with the probability of exceptional overall health at older ages. In the study of Japanese Americans, adjustment for risk factors that can mediate the effects of physical activity on human health, such as plasma glucose and triacylglycerol levels, hypertension, and BMI, is likely one explanation for the null association. Despite this, it is difficult to directly compare our findings with those of these studies because our cohort included only women, for whom physical activity patterns tend to be different from those of men. Nonetheless, similar to the Cardiovascular Health Study and the Harvard alumni study, we observed a strong, positive association between physical activity and exceptional survival at age 70 years or older in women. Our observations are also compatible with previous studies that used disability-free survival or self-rated overall health as a surrogate measure of successful survival.

In previous studies of successful survival, walking was not distinguished from more vigorous activities. While approximately 85% of Americans do not participate in any regular vigorous physical activities, 44% walk for exercise. Consistent with the literature on walking in relation to chronic diseases and other specific, adverse health

Table 2. Odds of Successful Survival Among Women 70 Years or Older in the Nurses’ Health Study by Physical Activity Level at Midlife

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total Physical Activity Quintile</th>
<th>P Value for Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 (Lowest)</td>
<td>2</td>
</tr>
<tr>
<td>Activity level, METs (h/wk), median (range)</td>
<td>0.9 (0.2-2.3)</td>
<td>3.6 (2.4-5.1)</td>
</tr>
<tr>
<td>Usual-adjusted survivor, No./No.</td>
<td>2603/213</td>
<td>2349/195</td>
</tr>
<tr>
<td>Age-adjusted model 1 [reference]</td>
<td>1.01 (0.83-1.24)</td>
<td>1.53 (1.28-1.84)</td>
</tr>
<tr>
<td>Multivariate model 1 [reference]</td>
<td>0.98 (0.80-1.20)</td>
<td>1.37 (1.13-1.65)</td>
</tr>
<tr>
<td>Multivariate model 1 [reference]</td>
<td>0.96 (0.78-1.18)</td>
<td>1.30 (1.08-1.57)</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CI, confidence interval;
METs, metabolic-equivalent tasks (measured in hours per week; each MET-hour is the caloric need per kilogram of body weight per hour of activity divided by the caloric need per kilogram of weight per hour at rest); NA, not applicable.

a Unless otherwise noted, data are reported as odds ratios (95% confidence intervals).

b Estimates of P value for linear trend are based on linear scores derived from the medians of each physical activity category.

c Multivariate model was adjusted for age at baseline (in years); education (registered nurse, bachelor’s degree, master’s degree, or doctorate); marital status (unmarried, married, widowed, separated, or divorced); 5 years of age; age at menopause; history of breast cancer; history of diabetes; history of heart disease; history of stroke; BMI (calculated as weight in kilograms divided by height in meters squared); smoking status (never, past, current 1-15 cigarettes/d or 15-24 cigarettes/d or ≥25 cigarettes/d); family history of heart disease, diabetes, or cancer (yes or no); dietary polyunsaturated to saturated fat ratio (in quintiles); intake of alcohol (in quintiles); and intake of fruits and vegetables and red meat for (in tertiles). For walking METs, vigorous physical activity METs were further adjusted.

d Further adjusted for BMI category (<18.5, 18.5-22.9, 23.0-24.9, or ≥25.0), history of hypertension (yes or no), and history of hypercholesterolemia (yes or no).
Table 3. Odds of Successful Survival Among Women 70 Years or Older in the Nurses’ Health Study by Walking Pace at Midlife

<table>
<thead>
<tr>
<th>Characteristic of Usual/successful survivors, No./No.</th>
<th>Easy (≤2.0 mph)</th>
<th>Moderate (2.0-2.9 mph)</th>
<th>Brisk/Very Brisk (≥3.0 mph)</th>
<th>P Value for Trend for Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usual/successful survivors, No./No.</td>
<td>1972/98</td>
<td>6244/672</td>
<td>3738/678</td>
<td>NA</td>
</tr>
<tr>
<td>Age-adjusted model</td>
<td>1 [Reference]</td>
<td>2.16 (1.74-2.68)</td>
<td>3.60 (2.89-4.48)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Multivariate model 1</td>
<td>1 [Reference]</td>
<td>1.90 (1.52-2.38)</td>
<td>2.68 (2.13-3.37)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Multivariate model 2</td>
<td>1 [Reference]</td>
<td>1.75 (1.40-2.19)</td>
<td>2.30 (1.82-2.91)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Walking METs ≤3.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usual/successful survivors, No./No.</td>
<td>1515/78</td>
<td>3474/322</td>
<td>1063/159</td>
<td>NA</td>
</tr>
<tr>
<td>Age-adjusted model</td>
<td>1 [Reference]</td>
<td>1.77 (1.37-2.28)</td>
<td>2.80 (2.11-3.72)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Multivariate model 1</td>
<td>1 [Reference]</td>
<td>1.69 (1.30-2.20)</td>
<td>2.50 (1.86-3.35)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Multivariate model 2</td>
<td>1 [Reference]</td>
<td>1.55 (1.19-2.01)</td>
<td>2.12 (1.58-2.85)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Walking METs &gt;3.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usual/successful survivors, No./No.</td>
<td>457/20</td>
<td>2770/350</td>
<td>2675/519</td>
<td>NA</td>
</tr>
<tr>
<td>Age-adjusted model</td>
<td>1 [Reference]</td>
<td>2.91 (1.83-4.61)</td>
<td>4.38 (2.77-6.92)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Multivariate model 1</td>
<td>1 [Reference]</td>
<td>2.58 (1.62-4.11)</td>
<td>3.46 (2.17-5.50)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Multivariate model 2</td>
<td>1 [Reference]</td>
<td>2.42 (1.51-3.86)</td>
<td>3.04 (1.91-4.85)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; METs, metabolic-equivalent tasks (measured in hours per week; each MET-hour is the caloric need per kilogram of body weight per hour of activity divided by the caloric need per kilogram of weight per hour at rest); NA, not applicable. 

a Regression models were adjusted for the same sets of covariates as detailed in the footnotes of Table 2 plus total physical activity (METs, hours per week; in quintiles) in multivariate models. 

b Unless otherwise noted, data are reported as odds ratios (95% confidence intervals).

outcomes,36-38 our results suggest that energy expenditure from walking at a moderate to brisk pace could also increase the likelihood of exceptional survival. Given that walking is a sustainable exercise that can often be easily incorporated into people’s daily schedules, our observations provide initial support for the consideration of walking in broad public health recommendations.

Importantly, in the present study, being physically active was associated with increased odds of successful survival for both lean and overweight women. This observation was consistent with previous findings by our research group that physical activity was related to a substantial reduction in risk of chronic diseases and premature death among participants with various body weights.10,34,39 Together, our data strongly support the notion that, regardless of body weight, engaging in physical activity may increase the probability of preserving optimal health. Meanwhile, our study also demonstrated that maintaining a healthy body weight and high physical activity levels simultaneously at midlife likely convey the highest odds of successful survival.

The strengths of the current study include a comprehensive measurement of overall health of aging women, large sample size, high follow-up rate, accurate self-reported incidence of chronic diseases, and validated methods to quantify physical and mental disabilities and cognitive function. Further unique aspects of our study are the focus on women (who live longer than men on average and thus merit particular attention in considering risk factors for successful survival) and the examination of walking (one of the more common types of activity among women). An additional strength derives from the multiple analyses conducted to consider possible reverse causation. For example, we excluded anyone with existing chronic diseases at baseline and also imposed an average 14-year lag period between exposure and outcome assessments—to both address reverse causation as well as the biologic likelihood that health and chronic conditions at older ages are influenced by lifestyle factors adopted at younger ages.

Our study also has several limitations. First, the generalizability of the current study may be limited to women who were primarily of European ancestry and largely healthy at midlife. Further research should be conducted in minority populations and populations with various specific health issues in earlier life. In addition, we...
considered successful survival as of age 70 years. Whether the observed associations can be generalized to populations at much older ages is unknown.

Second, although our questionnaire to measure physical activity has been validated in a similar population and has shown reasonable accuracy, the self-reported physical activity levels were inevitably subject to measurement error. However, since these data were collected before any of the study outcomes occurred, the measurement errors would most likely be nondifferential and bias true associations to the null.

Third, as in any observational study, residual confounding is also an alternative explanation of our observations. However, the strength and the dose-response gradient of the multivariate associations support a causal relationship between physical activity and successful aging. In addition, the homogeneity of our study population with respect to demographic characteristics and access to health care further reduce possibilities for confounding.

Fourth, we did not assess physical and mental health status at baseline. Therefore, long-term physical impairment or mental limitations might have biased our observations. However, when we restricted our analysis to women with sufficient function to engage in at least low to moderate physical activity levels at baseline, we observed similar associations.

Finally, approximately 16% of eligible women were excluded from the present analysis because of missing physical activity data at baseline. These participants had slightly higher BMIs; worse physical, cognitive, and mental status at older ages; and were less likely to be active at baseline than women who provided data on their physical activity. This combination could lead to bias toward the null.

In summary, the present study provides new evidence that midlife physical activity, including walking, is associated with increased odds of exceptional health among women who are initially healthy at midlife and survive to older ages. Since the American population is aging rapidly and nearly a quarter of Americans do not engage in any leisure-time activity, our findings appear to support federal guidelines regarding physical activity to promote health among older people and further emphasize the potential of activity to enhance overall health and well-being with aging. The notion that physical activity can promote successful survival rather than simply extend the lifespan may provide particularly strong motivation for initiating activity.

Accepted for Publication: October 12, 2009.

Correspondence: Qi Sun, MD, ScD, Department of Nutrition, Harvard School of Public Health, 655 Huntington Ave, Boston, MA 02115 (qisun@hsph.harvard.edu).

Author Contributions: Dr Grodstein had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Sun, Townsend, Okereke, Franco, Hu, and Grodstein. Acquisition of data: Hu and Grodstein. Analysis and interpretation of data: Sun, Townsend, Okereke, Franco, Hu, and Grodstein. Drafting of the manuscript: Sun and Franco. Critical revision of the manuscript for important intellectual content: Sun, Townsend, Okereke, and Grodstein. Statistical analysis: Sun, Townsend, and Okereke. Obtained funding: Franco, Hu, and Grodstein. Administrative, technical, and material support: Sun, Okereke, Franco, and Hu. Study supervision: Hu and Grodstein.

Financial Disclosure: None reported.

Funding/Support: This research was supported by research grants AG13482, AG15424, and CA40356 from the National Institutes of Health and grant DK46200 from the Pilot and Feasibility program sponsored by the Boston Obesity Nutrition Research Center. Dr Sun was supported by a postdoctoral fellowship from Unilever Corporate Research. Dr Townsend was supported by the Yerby Postdoctoral Fellowship Program. Dr Hu is a recipient of American Heart Association Established Investigator Award.

Role of the Sponsors: The funding sources had no role in the collection, analysis, and interpretation of the data or in the decision to submit the manuscript for publication.

Additional Contributions: Frans van der Ouderaa, PhD, provided insightful comments.

REFERENCES


