



Associations of Light, Moderate, and Vigorous Intensity Physical Activity with Longevity

The Harvard Alumni Health Study

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Physical activity is associated with better health; however, the optimal intensity of activity remains unclear. A total of 13,485 men (mean age, 57.5 years) from the Harvard Alumni Health Study reported their walking, stair climbing, and sports/recreation in 1977. Between 1977 and 1992, 2,539 died. After adjusting for the different activity components, distance walked and storeys climbed independently predicted longevity (p , trend = 0.004 and <0.001, respectively). Light activities (<4 multiples of resting metabolic rate (METs)) were not associated with reduced mortality rates, moderate activities (4–6 METs) appeared somewhat beneficial, and vigorous activities (≥ 6 METs) clearly predicted lower mortality rates (p , trend = 0.72, 0.07, and <0.001, respectively). These data provide some support for current recommendations that emphasize moderate intensity activity; they also clearly indicate a benefit of vigorous activity. *Am J Epidemiol* 2000;151:293–9.

exercise; longevity; mortality; obesity

There has been growing acceptance of the premise that a healthy lifestyle includes regular physical activity (1, 2). However, the optimal intensity of activity remains unclear. Studies of physical activity intensity and mortality have yielded inconsistent findings (3–10). Some suggest that only vigorous activity is associated with greater longevity; others also observe associations with nonvigorous (light and moderate grouped together) activity. Few investigators specifically have examined moderate activity and mortality (7, 10). Nonetheless, cognizant of the barriers to exercise among sedentary Americans (11) and because moderate activity improves cardiovascular risk factors (12–14), researchers recently have recommended moderate activity (15, 16), a departure from traditional prescriptions promoting vigorous exercise (17).

We previously compared the merits of nonvigorous and vigorous activity for longevity, following men

from 1962 through 1988 (9). Here, we update activity assessment in 1977 and follow men through 1992. Further, we separate light and moderate activities.

MATERIALS AND METHODS

Study subjects

The Harvard Alumni Health Study comprises men who matriculated as undergraduates, 1916–1950. Beginning in either 1962 or 1966, surviving alumni were sent health questionnaires periodically. For this investigation, the 17,835 alumni who returned a 1977 questionnaire were eligible. We excluded 3,706 men reporting physician-diagnosed cardiovascular disease, cancer, or chronic obstructive pulmonary disease on this questionnaire and 644 who did not provide information on physical activity and covariates, leaving 13,485 for the present study.

Assessment of physical activity and other predictors of mortality

On the 1977 questionnaire, alumni reported the daily number of blocks walked and flights of stairs climbed. They also reported their sports or recreational activities during the past year, the time spent per week, and the weeks per year of participation for each (18). This activity assessment is reasonably reliable and valid (19–25); for example, for energy expenditure, the test-retest correlation over 1 month was 0.72, while the

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Abbreviation: MET, multiple of resting metabolic rate.

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correlation for questionnaire estimates and estimates from activity records was 0.65 (25).

Walking one block daily rated 235 kJ/week (4.2 kJ = 1 kcal); climbing up and down one flight of stairs daily, 118 kJ/week. We assigned a multiple of resting metabolic rate (MET score) to each sport/recreation (26). Since the resting metabolic rate is approximately 4.2 kJ/kg of body weight/hour, we estimated the yearly energy expended on that activity by multiplying its MET score by 4.2, body weight, and hours per year of participation, dividing by 52 to obtain the average weekly expenditure. We summed energy expenditure from walking, stair climbing, and sports/recreation and defined five categories: <4,200, 4,200–8,400, 8,400–12,600, 12,600–16,800, and ≥16,800 kJ/week (31.2, 28.5, 18.4, 10.0, and 11.9 percent of men, respectively).

We additionally were interested in the specific activity components. We grouped men into approximate fourths of distance walked (1 block = 0.13 km; <5, 5–10, 10–20, and ≥20 km/week; 31.1, 21.6, 26.4, and 20.8 percent, respectively) and flights climbed (2 flights = 1 storey; <10, 10–20, 20–35, and ≥35 storeys/week; 22.9, 21.0, 20.6, and 35.5 percent, respectively). We divided sports/recreation into vigorous (≥6 METs; e.g., running/jogging, swimming laps, shoveling snow), moderate (4–6 METs; e.g., golfing, dancing, gardening), or light (<4 METs; e.g., bowling, boating, housekeeping) activities (27). We then defined five groups of vigorous energy expenditure using the same cutpoints as previously (9): <630, 630–1,680, 1,680–3,150, 3,150–6,300, and ≥6,300 kJ/week (52.3, 11.3, 10.0, 12.2, and 14.3 percent, respectively). We did likewise for moderate (66.7, 8.9, 7.3, 8.4, and 8.7 percent, respectively) and light (90.8, 4.2, 2.5, 1.5, and 1.0 percent, respectively) energy expenditure.

On the 1977 questionnaire, we also queried men regarding potential confounders in table 1.

Ascertainment of mortality

The Harvard Alumni Office maintains records of deceased alumni. Using this information, we obtained copies of death certificates for men dying from 1977 through 1992. Previously, we found a <1 percent loss to mortality follow-up (28). In 1998, we randomly sampled 500 alumni last contacted in 1988 and not known, according to our records, to have died through 1992. The National Death Index identified only two (0.4 percent) of the 500 as definitely deceased.

Statistical analysis

We examined the association between total energy expenditure and mortality using proportional hazards

TABLE 1. Characteristics of Harvard alumni (n = 13,485) at baseline, 1977

Characteristic	Mean	SD*
Age (years)	57.5	8.9
Energy expenditure (kJ/week)†	8,844	8,254
	No.	%
Cigarette habit		
Not smoking cigarettes	11,247	83.4
Smoking 1–20 cigarettes per day	1,118	8.3
Smoking >20 cigarettes per day	1,120	8.3
Alcohol habit		
Consuming <50 g/week	3,721	27.6
Consuming 50–199 g/week	5,042	37.4
Consuming ≥200 g/week	4,722	35.0
Quetelet's index		
<22.5 kg/m ²	2,973	22.1
22.5–23.5 kg/m ²	1,973	14.6
23.5–24.5 kg/m ²	2,582	19.1
24.5–26.0 kg/m ²	2,794	20.7
≥26 kg/m ²	3,163	23.5
Early (<65 years) parental death		
Neither parent dying early	8,920	66.2
One parent dying early	4,007	29.7
Both parents dying early	558	4.1
Physician-diagnosed hypertension	2,708	20.1
Physician-diagnosed diabetes mellitus	501	3.7

* SD, standard deviation.

† Estimated from walking, climbing stairs, and participating in sports or recreational activities.

models (29), controlling for age (single years), Quetelet's index, cigarette smoking, alcohol intake, and early parental death (all categorized as in table 1). Cumulative hazard plots provided no evidence against proportionality assumptions. We then separately examined men aged <55, 55–64, 65–74, and ≥75 years and two time periods, 1977–1985 and 1986–1992.

Next, instead of total energy expenditure, we included terms for its different components: walking, stair climbing, and light, moderate, and vigorous activities. That is, we assessed the independent association of each with mortality, regardless of the energy expended on other components.

Finally, to test a hypothesis that physically active but overweight men experience lower mortality rates than those inactive but thin (30, 31), we examined mortality rates among four groups classified by their activity (<4,200 vs. ≥4,200 kJ/week) and Quetelet's index (>25 vs. ≤25 kg/m² (32)).

RESULTS

Table 1 describes the characteristics of alumni. From 1977 through 1992, 2,539 men died. Age-adjusted mortality rates declined with greater total energy expenditure; this association persisted in multivariate analysis (table 2). Using life table analysis truncated at age 90 and accounting for the same potential confounders, we found that the most active group experienced, on average, 1.50 (95 percent confidence interval: 0.85, 2.15) added years of life compared with the least active. In primary analysis, we chose not to control for hypertension or diabetes mellitus as we considered these to be intermediate variables in the causal pathway (12, 14). When we adjusted for these variables in secondary analysis, relative risks were somewhat attenuated (1.00, 0.83, 0.77, 0.84, 0.77, respectively; *p*, trend < 0.001).

Among men aged <55, 55–64, 65–74, and ≥75 years at baseline, 397, 704, 1,057, and 381, respectively, died during follow-up. In all groups except the youngest, there were significant inverse trends between total energy expenditure and mortality (data not shown). For men aged <55 years, the multivariate relative risks were 1.00, 0.79, 0.75, 1.01, and 1.02, respectively (*p*, trend = 0.86). During both 1977–1985 (1,033 deaths) and 1986–1992 (1,506 deaths), mortality rates declined significantly with greater energy expenditure (data not shown).

Next, we investigated the different activity components. We noted declining age-adjusted mortality rates with greater distance walked, more stairs climbed, and greater energy expended on moderate or vigorous activities (figure 1). However, this was not observed for light activities. The inverse trend was less marked for moderate than vigorous activities.

TABLE 2. Rates* and relative risks† of all-cause mortality among Harvard alumni, 1977–1992, according to total energy expenditure‡ in 1977

Total energy expenditure (kJ/week)	No. of events	Mortality rate (per 1,000)	Relative risk
<4,200	1,032	15.6	1.00 Referent
4,200–<8,400	672	12.3	0.80 (0.72, 0.88)§
8,400–<12,600	368	11.3	0.74 (0.65, 0.83)
12,600–<16,800	215	12.0	0.80 (0.69, 0.93)
≥16,800	254	11.1	0.73 (0.64, 0.84)
<i>p</i> , trend		<0.001	<0.001

* Age adjusted.

† Adjusted for age, Quetelet's index, cigarette smoking, alcohol consumption, and early (<65 years) parental death.

‡ Estimated from walking, climbing stairs, and participating in sports or recreational activities.

§ Numbers in parentheses, 95% confidence interval.

Physically active individuals are likely to walk more, routinely climb stairs, and undertake different activities. Therefore, when assessing the independent association of each activity component with mortality, we accounted for participation in the other components. We attempted to account for this statistically by including terms for all components in a single multivariate model (table 3). Findings paralleled those from age-adjusted analyses; however, the inverse association with moderate activities now was of borderline significance.

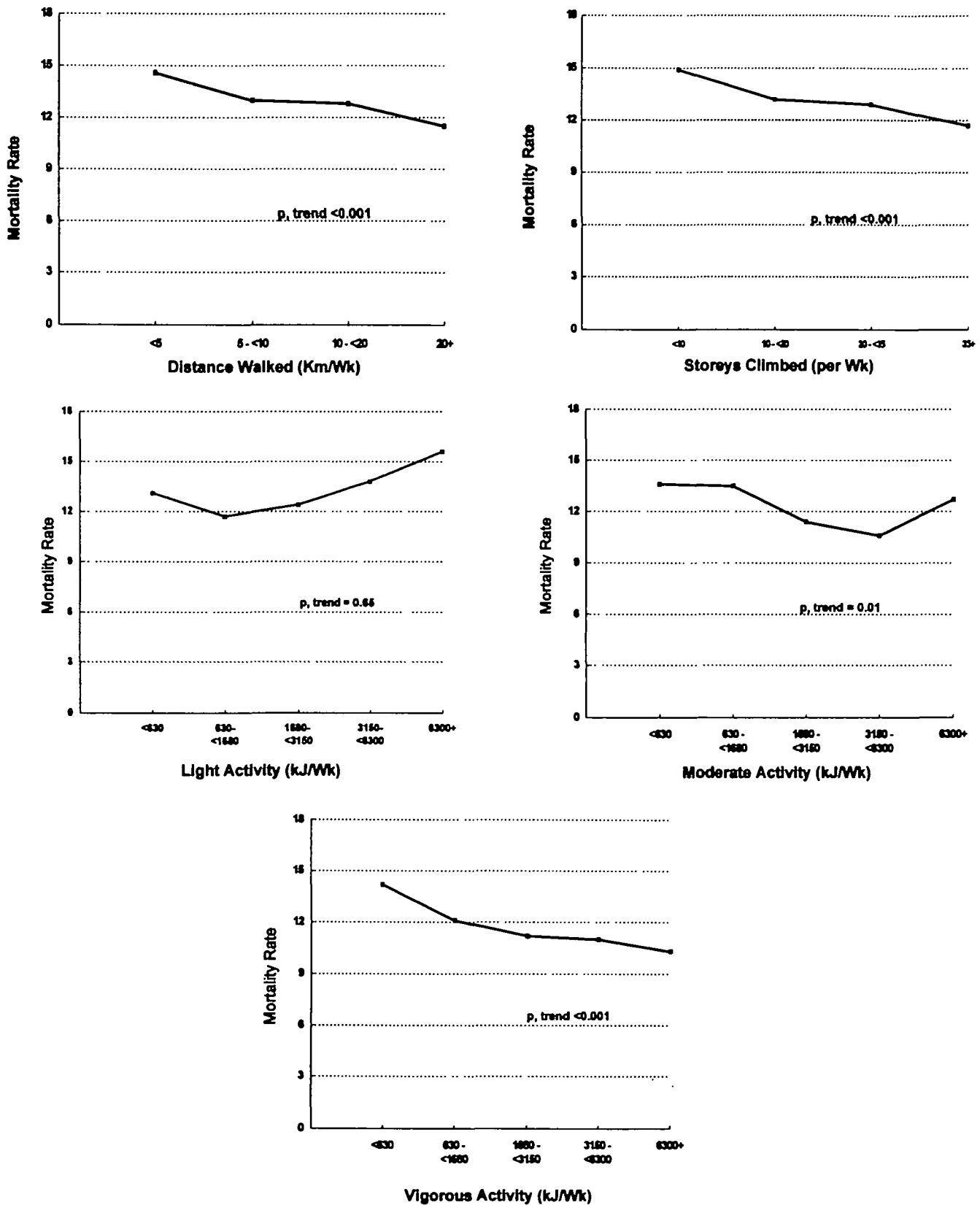
Finally, we examined four groups classified by physical activity (<4,200 vs. ≥4,200 kJ/week) and Quetelet's index (>25 vs. ≤25 kg/m²). We chose 4,200 kJ/week as a cutpoint because the largest decrement in mortality occurred at this break (table 2). In multivariate analysis, inactive, overweight men experienced the highest mortality rate, while active, not overweight men enjoyed the lowest (table 4). Mortality rates for inactive, not overweight men (14.8 per 1,000) and active, overweight men (13.3 per 1,000) did not differ significantly.

DISCUSSION

These data indicate that greater energy expenditure is associated with increased longevity. Walking and climbing stairs each independently predicted longevity. Participation in light activities, regardless of energy expenditure, appeared unassociated with mortality rates. In contrast, greater participation in moderate activities showed a trend toward lower mortality rates, while greater energy expended in vigorous activities clearly predicted lower mortality rates. Additionally, physical inactivity and overweight adversely affected longevity to a similar extent.

During both early and late follow-up, we observed significant inverse associations between physical activity and mortality rates. This minimizes the likelihood of bias due to unhealthy men who decreased their physical activity since they would likely die early during follow-up. While observational studies cannot prove cause and effect, biologically, it appears convincing for physical activity to postpone mortality, especially from cardiovascular disease, since exercise improves blood pressure (12), lipoprotein levels (13), and glucose tolerance (14, 33); enhances cardiac mechanical and metabolic function (34); and improves homeostatic factors (35).

Few studies have examined the kinds and intensities of physical activity optimal for health. In previous analyses of alumni (36), as well as among Japanese-American men (37) and Dutch men and women (38), walking was associated with greater longevity. Moderate activity appeared beneficial for longevity



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FIGURE 1. Age-adjusted mortality rates (per 1,000) among Harvard alumni, 1977–1992, according to different physical activity components in 1977. Light activities required <4 times the resting metabolic rate (MET), moderate activities required 4–<6 METs, and vigorous activities required ≥ 6 METs.

TABLE 3. Relative risks* of all-cause mortality among Harvard alumni, 1977–1992, according to different physical activity components† in 1977

Physical activity component	No. of events	Relative risk	95% confidence interval
Walking (km/week)			
<5	850	1.00	Referent
5–<10	514	0.91	0.82, 1.02
10–<20	658	0.92	0.83, 1.01
≥20	517	0.84	0.75, 0.94
<i>p</i> , trend = 0.004			
Climbing stairs (storeys/week)			
<10	778	1.00	Referent
10–<20	497	0.89	0.80, 1.00
20–<35	494	0.89	0.79, 0.99
≥35	770	0.82	0.74, 0.91
<i>p</i> , trend < 0.001			
Light activities (kJ/week)			
<630	2,316	1.00	Referent
630–<1,680	93	0.91	0.74, 1.12
1,680–<3,150	54	0.93	0.71, 1.22
3,150–<6,300	42	1.07	0.79, 1.46
≥6,300	34	1.17	0.83, 1.64
<i>p</i> , trend = 0.72			
Moderate activities (kJ/week)			
<630	1,762	1.00	Referent
630–<1,680	185	1.05	0.90, 1.23
1,680–<3,150	149	0.89	0.75, 1.05
3,150–<6,300	175	0.82	0.70, 0.96
≥6,300	268	0.97	0.85, 1.10
<i>p</i> , trend = 0.07			
Vigorous activities (kJ/week)			
<630	1,731	1.00	Referent
630–<1,680	226	0.89	0.77, 1.02
1,680–<3,150	176	0.82	0.70, 0.96
3,150–<6,300	194	0.82	0.71, 0.96
≥6,300	212	0.77	0.67, 0.89
<i>p</i> , trend < 0.001			

* Adjusted for age, Quetelet's index, cigarette smoking, alcohol consumption, and early (<65 years) parental death. Additionally, each component of physical activity was adjusted for the other four components.

† Light activities required <4 times the resting metabolic rate (MET), moderate activities required 4–<6 METs, and vigorous activities required ≥6 METs.

among alumni in this study, as well as among other US men (7) and women (10). As with this study, studies of British civil servants (3, 4), Finnish men (8), and US railroad workers (5) also indicate a clear association between vigorous activity and longevity. Additionally, there appears to be a continuum of benefit for cardiovascular risk factors with increasing amounts and intensity of physical activity (39–43).

Strengths of this study include a detailed activity assessment and thorough follow-up. One limitation is that assessment appears less valid for light and moderate than vigorous activities (25). Hence, the weaker

relation with moderate activity and the lack of association for light activity might reflect less precise assessment.

We assessed activity only once, in 1977, and did not account for changes over time. Among alumni, correlations between physical activity assessed over 11–15 years have only been moderate, on the order of 0.4 (18). Therefore, the resulting misclassification likely attenuated observed relative risks. Additionally, some may have neglected to report activities not perceived as “sports” or “recreation,” leading to underestimation of energy expenditure.

TABLE 4. Rates* and relative risks* of all-cause mortality among Harvard alumni, 1977–1992, according to physical activity† and weight‡ in 1977

Physical activity	Weight	No. of events	Mortality rate (per 1,000)	Relative risk
Inactive	Overweight	421	16.4	1.00 Referent
Inactive	Not overweight	611	14.8	0.90 (0.79, 1.02)§
Active	Overweight	568	13.3	0.80 (0.71, 0.91)
Active	Not overweight	939	11.1	0.67 (0.60, 0.75)

* Adjusted for age, cigarette smoking, alcohol consumption, and early (<65 years) parental death.

† Estimated from walking, climbing stairs, and participating in sports or recreational activities. Inactive men expended <4,200 kJ/week; active men, ≥4,200 kJ/week.

‡ Overweight men were those with Quetelet's index of >25 kg/m²; not overweight men, Quetelet's index of ≤25 kg/m².

§ Numbers in parentheses, 95% confidence interval.

Finally, we did not collect detailed dietary information in 1977. However, using diet assessed in 1988, the proportion of total energy consumed as fat or saturated fat did not differ across categories of light, moderate, or vigorous energy expenditure, making it unlikely for these dietary factors to confound the associations seen.

In conclusion, these data provide some support for current recommendations that emphasize moderate activities, such as brisk walking. Further, they clearly indicate an association between vigorous activity and longevity. Thus, while the message of moderate activity may be more palatable for those recalcitrant to exercise, vigorous activity should receive no less emphasis among those for whom such activity is not contraindicated: In today's world where time is a precious commodity, a half-hour of vigorous exercise expends as much energy as does moderate activity carried out for 2–3 times as long.

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