Elevated systolic and diastolic blood pressure are associated with increased risk for stroke, coronary heart disease, congestive heart failure, peripheral vascular disease, and renal disease. In patients with cardiovascular disease (CVD), elevated systolic blood pressure is one of the strongest predictors of secondary CVD events. Lifestyle modifications such as increasing physical activity, losing weight, and reducing sodium are recommended for treating hypertension. Most previous studies have reported that higher levels of physical activity are related to a reduced risk of incident hypertension. The physical activity measures employed in these studies have been based on self-reported questionnaire measures. Self-reported measures of physical activity are only modestly correlated with objective measures obtained using criterion methods. One approach to objectively assess recent physical activity level is to assess cardiorespiratory fitness (CRF). However, few prospective studies have investigated the relationship between baseline CRF levels and the development of hypertension in initially normotensive individuals. Therefore, it is important to understand how or if different types of physical activity and CRF, an objective reproducible measure that reflects the functional consequences of recent physical activity habits, disease, and genetics, have different effects on the incidence of hypertension.

To the best of our knowledge, only one study has simultaneously examined CRF, vigorous exercise, and incident hypertension. However, this report was limited by only studying runners. Therefore, the goal of the current study was to evaluate the independent and joint associations among fitness, various types of physical activity, and incident hypertension in a cohort of men enrolled in the Aerobics Center Longitudinal Study (ACLS).

METHODS

Participants. The ACLS is a prospective study of the health effects of physical activity and fitness. Data were obtained from patients of the Cooper Clinic, a preventive medicine clinic in Dallas, Texas. Participants were self- or employer referred to the clinic for various services such as preventive medical examinations and health, nutrition, and exercise counseling. Participants for the current analysis were 16,601 men aged 20–82 years who completed a baseline examination during 1970–2002 and were followed for hypertension incidence. Physical activity was self-reported and CRF was quantified from the duration of a maximal treadmill test.

RESULTS

A total of 2,346 men reported hypertension during a mean 18 years of follow-up. Event rates per 10,000 man-years adjusted for age and examination year were 86.2, 76.6, and 66.7 across physical activity groups of sedentary, walker/jogger/runner (WJR), and sport/fitness, respectively, and 89.8, 78.4, and 64.6 for low, middle, and high CRF, respectively (trend \( P < 0.0001 \)). These associations persisted after further adjustment for body mass index (BMI), smoking, alcohol intake, resting systolic blood pressure, baseline health status, family history of diseases, and survey response patterns.

CONCLUSION

Both physical activity and CRF are associated with lower risk of developing hypertension in a graded fashion. These findings provide a basis for health professionals to emphasize the importance of participating in regular physical activity to improve fitness for the primary prevention of hypertension in men.
Physical Activity and CRF Predict Incident Hypertension

20–82 years who completed a health examination during 1970–2002. At baseline, all participants were free of known CVD and cancer. They also reported no physician diagnosis of hypertension and had resting blood pressure of <140/90 mm Hg at baseline. A large majority of participants were Caucasian (97%) and from middle and upper socioeconomic strata. Very few participants were from other ethnic groups (0.6% African American and 2.4% Asians and others). All participants provided written consent to participate in the examination and in the follow-up research. The study protocol was reviewed and approved annually by the Cooper Institute Institutional Review Board.

Clinical examination. Clinical examinations were completed after a 12-h fast and have been described in detail elsewhere. Briefly, information pertaining to personal and family health histories, personal health habits, and demographic information was obtained from standardized medical history questionnaires. Height and weight were measured in light clothing and without shoes using a standard clinical scale and stadiometer. Body mass index (BMI) was calculated as kg/m². Seated blood pressure was recorded as the first and fifth Korotkoff sounds using auscultation methods. Fasting serum samples were analyzed for lipids and glucose using standardized automated bioassays at the Cooper Clinic Laboratory, which participated in and met quality control criteria of the Centers for Disease Control and Prevention Lipid Standardization Program. Diabetes mellitus was defined as fasting plasma glucose concentration of 126 mg/dl or greater, a history of physician diagnosis, or insulin use. Hypercholesterolemia was defined as total cholesterol of 240 mg/dl or greater. Personal history of CVD (myocardial infarction or stroke), information on smoking habits (current smoker or not), alcohol intake (drinks per week), family history of CVD or hypertension, and physical activity habits (sedentary, walker/jogger/runner (WJR), and sport/fitness participants) were obtained from a standardized questionnaire.

Physical activity. Physical activity status was categorized into three mutually exclusive groups according to the usual type of physical activity reported during the preceding 3 months. Sedentary individuals were those participants who answered “no” to all activity questions (running, walking, jogging, bicycling, swimming, racquet sports, and other strenuous sports). Sport/fitness activity (hereafter referred to as “sport”) participants were those who answered “no” to the run/walk/jog question but “yes” to a wide range of questions about participation in racquet sports, other strenuous sports (football, basketball, softball, etc.), cycling, stair climbing, cross-country skiing, aerobic dancing, or swimming. Due to the small number of participants and hypertension events in different sport groups, it was not possible to evaluate separate sport categories. We classified participants as WJR if they answered “yes” to the question, “Have you participated in a run/walk/jog program in the last three months?”

CRF. CRF was quantified as the duration of a symptom-limited maximal treadmill exercise test using a modified Balke protocol. The treadmill test began with the patient walking 88 m/min at 0% grade. At the end of the first minute, elevation was increased to 2% and thereafter increased 1% per minute until the 25th min. For those who were able to continue past 25 min, the treadmill speed was increased by 5.4 m per minute, for each minute after the 25th. Exercise duration on this protocol is highly correlated with measured maximal oxygen uptake in men (r = 0.92). The test endpoint was volitional exhaustion or termination by the supervising physician. Maximal metabolic equivalents (METs, 1 MET = 3.5 ml O₂ uptake/kg/min) were estimated from the final treadmill speed and grade. We categorized men into thirds depending on age-specific (20–29, 30–39, 40–49, 50–59, and ≥60 years) distributions of treadmill time.

Morbidity surveillance. The incidence of hypertension was ascertained from responses to mail-back health surveys in 1982, 1986, 1990, 1995, 1999, and 2004. The aggregate survey response rate across all survey periods in the ACLS is ~65%. Nonresponse bias is a concern in epidemiological surveillance. This issue has been investigated in the ACLS, and found not to present a major source of bias. Baseline health histories and clinical measures were similar between responders and nonresponders and between early and late responders. The endpoint was defined as a participant report of a physician diagnosis of hypertension and has been described in detail elsewhere. We previously verified the accuracy of self-reported, physician-diagnosed hypertension in this cohort and observed 98% sensitivity and 99% specificity. Our methods of case ascertainment are similar to those used in other established epidemiologic studies on hypertension.

Statistical analysis. Baseline characteristics of the population were calculated for physical activity and CRF categories. Differences in covariates were tested using analysis of variance tests for continuous variables and chi-square tests for categorical variables. We performed an overall F-test for one-way analysis of variance and then compared two pairs of groups (sedentary vs. WJR or sport, low vs. middle or high fitness), which had been planned in advance, with the least-squares means procedure if the overall F-test was statistically significant. We used Fisher’s Z transformation to examine the correlations among physical activity categories and exercise duration by assessing Pearson coefficients (Table 3). Treadmill test duration was compared across the three physical activity groups using general linear models with Bonferroni post hoc comparison tests (Figure 1). Follow-up time among noncases was computed as the difference between the date of the baseline examination and the date of the last returned survey in which the participant reported being free of hypertension. Follow-up time among cases was computed as the difference between the baseline examination date and the reported date of the hypertension event. If a diagnosis date was not provided, we used the midpoint between the date of the case-finding survey and either
the baseline examination date or the date of the last returned survey in which the participant reported being free of hypertension. Cox proportional hazards regression analysis was used to estimate hazard ratios, 95% confidence intervals, and hypertension incidence rates (per 10,000 man-years) according to exposure categories. Multivariable analyses included controls for baseline measures: age (in years), BMI (kg/m²), smoking status (current smoker or not), alcohol intake (≥5 drinks/wk or not), resting systolic and diastolic blood pressure (mm Hg), medical conditions (the presence or absence, separately measured, of diabetes or hypercholesterolemia), and family history of CVD or hypertension (present or not for each). We also constructed indicator variables (yes/no) for each survey period to account for differences in survey response patterns in order to reduce the influence of ascertainment bias. To standardize for surveillance period and length of follow-up, we entered these variables, as well as the year of the baseline examination, into our analyses as covariables. Cumulative hazard plots grouped by exposure suggested no appreciable violations of the proportional hazards assumption. Finally, we examined the joint effects of physical activity (sedentary, WJR, and sport) and CRF (low, middle, and high) on incident hypertension. For this analysis, we created nine activity-fitness combination categories. We compared the effect of each combination of activity and fitness status (sedentary-low, sedentary-middle, sedentary-high, WJR-low, WJR-middle, WJR-high, sport-low, sport-middle, and sport-high) with the referent group (sedentary-low). We also performed additional analyses using logistic regression.

![Figure 1](https://academic.oup.com/ajh/article-abstract/22/4/417/155280)

**Figure 1** | Associations between cardiorespiratory fitness (expressed by treadmill test duration in minutes) and physical activity categories. *Adjusted for age, examination year, survey response patterns, body mass index (kg/m²), current smoking (yes or no), alcohol intake (≥5 drinks/wk, yes or no), resting systolic and diastolic blood pressure (mm Hg), hypercholesterolemia (yes or no), diabetes (yes or no), family history of hypertension (present or not), and family history of cardiovascular disease (present or not). **Reference: WJR, walker/jogger/runner.

<table>
<thead>
<tr>
<th>Physical activity categories</th>
<th>Sedentary</th>
<th>WJR</th>
<th>Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>5,030</td>
<td>8,400</td>
<td>3,171</td>
</tr>
<tr>
<td>Age (mean ± s.d., years)</td>
<td>43.5 ± 9.1</td>
<td>43.8 ± 9.4</td>
<td>44.1 ± 9.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Waist circumference (mean ± s.d., cm)</td>
<td>93.9 ± 14.3</td>
<td>88.4 ± 15.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>90.2 ± 16.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Body mass index (mean ± s.d., kg/m²)</td>
<td>26.0 ± 3.4</td>
<td>25.2 ± 2.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.8 ± 3.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Exercise tolerance (mean ± s.d., METs)</td>
<td>10.7 ± 1.9</td>
<td>13.1 ± 2.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.8 ± 2.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Treadmill test duration (mean ± s.d., min)</td>
<td>16.0 ± 4.0</td>
<td>20.9 ± 4.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.3 ± 4.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lipids (mean ± s.d., mg/dl)</td>
<td>Total cholesterol</td>
<td>213.5 ± 38.8</td>
<td>203.0 ± 37.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>HDL-C</td>
<td>43.8 ± 11.6</td>
<td>47.8 ± 12.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>46.0 ± 11.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Triglycerides</td>
<td>140.0 ± 101.7</td>
<td>112.9 ± 80.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>124.2 ± 78.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fasting blood glucose (mean ± s.d., mg/dl)</td>
<td>100.2 ± 17.2</td>
<td>98.2 ± 12.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>98.5 ± 13.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Blood pressure (mean ± s.d., mm Hg)</td>
<td>Systolic</td>
<td>117 ± 9</td>
<td>117 ± 10</td>
</tr>
<tr>
<td>Diastolic</td>
<td>77 ± 7</td>
<td>76 ± 7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77 ± 7</td>
</tr>
<tr>
<td>Current smoker (%)</td>
<td>22.1</td>
<td>10.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Alcohol consumption (≥5 drinks/week) (%)</td>
<td>33.4</td>
<td>38.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.9</td>
</tr>
<tr>
<td>Hypercholesterolemia (%)</td>
<td>22.8</td>
<td>14.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diabetes (%)</td>
<td>4.6</td>
<td>2.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Family history of hypertension (%)</td>
<td>8.6</td>
<td>11.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Family history of CVD (%)</td>
<td>3.4</td>
<td>4.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

SI conversion factors: To convert total cholesterol and HDL-C values to mmol/l, multiply by 0.0259; triglycerides values to mmol/l by 0.0113; glucose values to mmol/l by 0.0555. CVD, cardiovascular disease; HDL-C, high-density lipoprotein cholesterol; METs, maximal metabolic equivalents achieved during the treadmill test; WJR, walker/jogger/runner.

<sup>a</sup>Significantly different from sedentary individuals (P < 0.05).
to verify the results to account for the possible inaccuracy of the diagnostic date of incident hypertension. All $P$ values were calculated assuming 2-sided alternative hypotheses; $P$ values <0.05 were taken to indicate statistically significant comparisons. All analyses were performed using SAS statistical software, version 9.1 (SAS, Cary, NC).

RESULTS

The baseline characteristics of the study sample by their physical activity and CRF measures are presented in Table 1 and Table 2, respectively. The proportion of men who participated in the sport category was 19.1%. There were significant differences in the three physical activity groups on all of the baseline variables (Table 1). The average duration of WJR per week was 11 miles (data not shown). Participants with lower CRF values tended to be older, were less active, had higher BMI values, and were more likely to have major CVD risk factors, such as hypercholesterolemia, diabetes, and less likely to have family history of hypertension or CVD (Table 2). Table 3 shows that all three activity groups and treadmill exercise duration were significantly correlated. Each of the activity groups was modestly correlated with CRF levels. After adjusting for the potential confounders, treadmill test duration within WJR and sport groups was significantly higher compared with sedentary men, respectively (Figure 1).
Physical Activity and CRF Predict Incident Hypertension

Table 4 | Rates and hazard ratios for developing hypertension, according to baseline physical activity and cardiorespiratory fitness (CRF) category

<table>
<thead>
<tr>
<th>Cases</th>
<th>Man-years</th>
<th>Ratea</th>
<th>Model 1b HR (95% CI)</th>
<th>Model 2c HR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>863</td>
<td>101,355</td>
<td>86.2</td>
<td>1.0 (Referent)</td>
</tr>
<tr>
<td>WJR</td>
<td>1131</td>
<td>147,000</td>
<td>76.6</td>
<td>0.82 (0.75–0.90)</td>
</tr>
<tr>
<td>Sport</td>
<td>352</td>
<td>51,878</td>
<td>66.7</td>
<td>0.74 (0.65–0.84)</td>
</tr>
<tr>
<td>P for linear trend</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>CRF thirds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>969</td>
<td>106,884</td>
<td>89.8</td>
<td>1.0 (Referent)</td>
</tr>
<tr>
<td>Middle</td>
<td>765</td>
<td>99,151</td>
<td>78.4</td>
<td>0.82 (0.75–0.90)</td>
</tr>
<tr>
<td>High</td>
<td>612</td>
<td>94,239</td>
<td>64.6</td>
<td>0.64 (0.57–0.71)</td>
</tr>
<tr>
<td>P for linear trend</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
</tbody>
</table>

CI, confidence interval; CVD, cardiovascular disease; HR, hazard ratio; WJR, walker/jogger/runner.

aRate per 10,000 man-years adjusted for age and examination year. bModel 1: adjusted for baseline age, examination year, and survey response pattern. cModel 2: adjusted for all variables in Model 1 plus body mass index (kg/m²), current smoking (yes or no), alcohol intake (25 drinks/wk, yes or no), resting systolic and diastolic blood pressure (mm Hg), hypercholesterolemia (yes or no), diabetes (yes or no), family history of hypertension (present or not), and family history of CVD (present or not).

Over a mean (s.d., range) 18.1 (8.1, 1–34) years of follow-up (300,312 man-years), we documented 2,346 incident cases of hypertension. Age and examination year-adjusted hazard ratios and event rates (per 10,000 man-years) for the categories of physical activity and thirds of CRF are presented in Table 4. Across physical activity groups, the event rates were 86.2, 76.6, and 66.7 in men who were sedentary, who participated in WJR activity, and who participated in sport activity, respectively. After further adjusting for survey response pattern, the men in the WJR group had 13% lower, and men in the sport category had 24% lower hypertension risks than sedentary men. Additional adjustment for BMI, smoking, alcohol intake, systolic and diastolic blood pressure, hypercholesterolemia, diabetes, and family history of hypertension or CVD did not significantly change the results. For CRF, an inverse gradient (P trend < 0.0001) of incident hypertension event rates was observed across incremental thirds of CRF groups. After adjustment for the same covariables, men with middle and high CRF had an 11% and 29% lower hypertension risk than did men with low CRF (P trend < 0.0001).

Finally, we analyzed the joint associations of physical activity and CRF with incident hypertension. Figure 2 shows the age- and examination year-adjusted event rates across physical activity (sedentary, WJR, and sport/fitness activity) and CRF (low, middle, and high) categories, which resulted in nine activity-CRF groups. The event rate in the high CRF men who participated in the sport/fitness activities was the lowest among the nine combination groups. The adjusted incidence rate was inversely related to CRF within each of the physical activity categories (all P < 0.05 for trends). However, there was no association between WJR or sport/fitness activity groups and outcomes within the low and middle CRF groups, compared with the sedentary men (P > 0.05 for each). There was an inverse association between sport group and outcome within the high CRF group, compared with the sedentary men (P = 0.003). The results were similar when we performed logistic regression models instead of Cox regression models. Therefore, only the proportional hazard analysis results are shown.

DISCUSSION

The principal finding of this report is that both higher CRF and participating in sport or walking/jogging/running decrease the risk of developing hypertension in comparison with low fitness or sedentary lifestyle, respectively. We believe that this is the first study that has evaluated both fitness and different types of activity in relation to risk of incident hypertension. Sedentary men had the highest incidence rate of hypertension,
while men who participated in sport activity had the lowest rates of incident hypertension. After adjustment for several potential confounders, the inverse association between the sport or WJR group and the risk of hypertension was attenuated, but remained significant. These results suggest that regular activity like walking/jogging/running or participating in sports, appears to reduce the risk of developing hypertension.

The data reported here also show an inverse dose-response association between CRF and risk of incident hypertension in initially normotensive and healthy middle-aged men. The association persisted after extensive adjustment for potential confounding factors. The inverse association also persisted when stratified on the physical activity groups. This further strengthens the evidence that there is an inverse relationship between higher CRF levels and lower risk of hypertension.

Our results are consistent with several large, epidemiological studies examining the association between physical activity and the incidence of hypertension.

The Harvard Alumni Study showed that men who regularly participated in sports activity had a 19–29% lower risk of developing hypertension. Lack of strenuous exercise independently predicted a higher risk of hypertension. Alumni who did not participate in vigorous physical activity had a 35% greater risk of hypertension than those who did. In a later analysis, Paffenbarger and Lee concluded that lack of moderately vigorous physical activity, being overweight, and family history of hypertension increased the risk of developing hypertension. In the Atherosclerosis Risk in Communities Study, Pereira et al. showed an inverse association between leisure-time physical activity and incidence of hypertension in 7,459 African American and Caucasian adults aged 45–65 years between 1987 and 1995. Caucasian men in the highest quartiles of sports and leisure activity had 23% and 34% lower rates of hypertension in men.17 and in women.18 Barlow et al. examined the rates of incident hypertension. After adjustment for several potential confounders, the inverse association between physical activity and hypertension was significant. These results support the hypothesis that middle and high fitness levels favorably influence hypertension risk across different types of physical activity. These findings are in agreement with a recent study that found that higher CRF reduces the odds for hypertension, independent of physical activity, and is an important risk factor separate from physical activity.19

Several mechanisms are speculated regarding the inverse relationship between physical activity and hypertension, though these possible mechanisms were beyond the scope of this investigation. Regular physical activity can reduce norepinephrine. The reduction in norepinephrine was associated with decreased sympathetic nervous system activity was decreased. This in turn may cause reductions in vasoconstriction and total peripheral resistance. Other studies have found that nitric oxide production, which influences endothelial cell-dependent vasodilation, is increased through exercise training. Increased insulin sensitivity was also a possible pathway by which physical activity influences blood pressure.

Strengths of the current study include the extensive baseline examination to detect subclinical disease, the large size of the cohort, the relatively long follow-up period, the assessment of different types of physical activity, and the objective measures of CRF levels, which were quantified from the use of maximal exercise testing. Participation in certain sports may be confounded by education level, health knowledge, and other sociodemographic factors. However, a majority of the participants in this study were Caucasian, well educated, middle to upper class, which limits the generalizability of the study’s findings, although this limitation should not affect the study’s internal validity. There was insufficient information about hypertension medication use or dietary habits to include these factors in the analysis. Due to the widespread geographic distribution of patients evaluated at the Cooper Clinic, we were unable to verify all reported hypertension events. However, based on a random sample of verified events, it appears that an acceptable level of agreement exists between the participant’s self-reported history and his medical records. In terms of exposure assessment, we classified men at study enrollment, but in the present analysis we were unable to evaluate the effect of changes in physical activity and fitness over time on our outcomes. It is possible that sedentary or low fit men increased their activity or fitness levels at some point in the follow-up interval. In addition, others may have experienced decreases in these characteristics. Such misclassification of exposure would likely lead
to underestimating the magnitude of the association observed in the present study. We did not have sufficient information on frequency and intensity reported in the WJR or sports group. Therefore, we could not account for exercise volume in each of the activity groups. Future studies should include such information whenever possible.

In conclusion, our prospective findings in a large cohort of initially normotensive and healthy middle-aged men show that both physical activity and CRF are independent predictors of incident hypertension in men. Lifestyle modification has long been encouraged particularly for those with hypertension as well as for the entire population.42 We believe health professionals should counsel their sedentary patients to become physically active through participating in regular physical activity, such as walking, jogging, bicycling, swimming, and playing sports,43 and to improve their fitness for the primary prevention of hypertension.

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