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Physical activity and physiological cardiac remodelling in a community setting: the Multi-Ethnic Study of Atherosclerosis (MESA)

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Abstract

Objective—To evaluate the association of physical activity with left ventricular structure and function in the general population in a community setting.

Design—Cross-sectional study.

Setting—The Multi-Ethnic Study of Atherosclerosis (MESA), a population-based study of subclinical atherosclerosis.

Participants—A multiethnic sample of 4992 participants (aged 45–84 years; 52% female) free of clinically apparent cardiovascular disease.

Interventions—Physical activity induces beneficial physiological cardiac remodelling in a cross-sectional study of non-athlete individuals.

Main Outcome Measures—Left ventricular mass, volumes and function were assessed by cardiac magnetic resonance imaging. Physical activity, defined as intentional exercise and total

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moderate and vigorous physical activity, was assessed by a standard semiquantitative questionnaire.

Results—Left ventricular mass and end-diastolic volume were positively associated with physical activity (eg, 1.4 g/m² (women) and 3.1 g/m² (men) greater left ventricular mass in the highest category of intentional exercise compared with individuals reporting no intentional exercise; $p = 0.05$ and $p < 0.001$, respectively). Relationships were non-linear, with stronger positive associations at lower levels of physical activity (test for non-linearity; $p = 0.02$ and $p = 0.03$, respectively). Cardiac output and ejection fraction were unchanged with increased physical activity levels. Resting heart rate was lower in women and men with higher physical activity levels (eg, −2.6 beats/minute lower resting heart rate in the highest category of intentional exercise compared with individuals reporting no intentional exercise; $p < 0.001$).

Conclusions—In a community-based population free of clinically apparent cardiovascular disease, higher physical activity levels were associated with proportionally greater left ventricular mass and end-diastolic volume and lower resting heart rate.

Physical activity is beneficial for cardiovascular health by lowering the risk of coronary heart disease, high blood pressure, adverse blood lipid profile and obesity.^{1,2} Recent guidelines for physical activity from the US Department of Health and Human Services showed an inverse association between relative risk for premature death and moderate to vigorous physical activity.¹ It is possible that this inverse association may be reflected by cardiac remodelling.

The physiological adaptation of the heart to physical training has been studied primarily in high performance athletes, usually using echocardiography. Commonly described as the “athlete's heart”,^{3,4} the left ventricle has been shown to adapt by increasing end-diastolic diameter and myocardial mass with decreasing resting heart rate in response to intense physical training.^{3–5} The relationship between physical activity and increased left ventricular mass has previously been reported to be significant for young men but not for women and older men in population-based samples.^{6,7} To date, little is known about the relationship of common levels of physical activity to myocardial size (except left ventricular mass), mass to volume ratio (a measure of myocardial remodelling) and function in non-athletic populations. As adverse myocardial remodelling is a strong predictor of cardiovascular morbidity and mortality,^{8,9} it is important to understand the impact of modifiable lifestyle factors, such as physical activity, on cardiac performance. Similarly, exercise training has also been found to be beneficial in chronic heart failure patients, with small improvements in cardiomegaly and stroke volume.¹⁰

The purpose of this study was to examine the relationship between physical activity and left ventricular size and function in a community-based multi-ethnic sample of women and men. We also sought to examine ethnic and gender differences in left ventricular size and function in response to physical activity.

Materials and Methods

Study sample

The Multi-Ethnic Study of Atherosclerosis (MESA) has previously been described.¹¹ In brief, between July 2000 and August 2002, 6814 participants (aged between 45 and 84 years) who identified themselves as white, African-American, Hispanic, or Chinese and were free of clinically apparent cardiovascular disease were recruited from six US communities: Baltimore City and Baltimore County, Maryland; Chicago, Illinois; Forsyth County, North Carolina; Los Angeles County, California; Northern Manhattan and the Bronx, New York; and St. Paul, Minnesota. Consenting participants underwent a cardiac

magnetic resonance imaging (MRI) of the heart a median of 16 days after the baseline evaluation; 95% were completed by 11 weeks after the baseline examination. The institutional review boards at all participating centres approved the study, and all participants gave informed consent.

Baseline examination

All participants underwent an extensive baseline evaluation including clinical history, physical examination, laboratory tests including fasting glucose level (analytical coefficient of variation (CV) ~1%), total cholesterol (CV <2%), triglycerides (CV <4%), high-density lipoprotein (HDL) cholesterol (CV <3%) plus calculated low-density lipoprotein (LDL) cholesterol,¹² and anthropometric measurements. Standard questionnaires were used to obtain information about smoking history and medication usage for high blood pressure, high cholesterol or diabetes. Blood pressure was measured three times in the seated position with a Dinamap device (Critikon, Tampa, Florida, USA); hypertension was defined as systolic blood pressure of 140 mm Hg or greater and diastolic blood pressure of 90 mm Hg or greater using the average of the last two measurements, self-reported hypertension or the use of medication for hypertension. Diabetes was defined as fasting blood glucose of 126 mg/dl or greater or the use of hypoglycaemic medication. Heart rate obtained from ECG was defined as resting heart rate. Body surface area was calculated as $0.20247 \times [\text{height (m)}^{(0.725)}] \times [\text{weight (kg)}^{(0.425)}]$ from weight measured to the nearest 0.5 kg (in light clothing) and height to the nearest 0.1 cm.

Physical activity survey

Physical activity levels were assessed using the MESA Typical Week Physical Activity Survey (TWPAS), adapted from the Cross-Cultural Activity Participation Study¹³ to determine the time and frequency spent in various physical activities during a typical week in the past month. Nine physical activity categories (household chores, lawn/yard/garden/farm, care of children/adults, transportation, walking (not at work), dancing and sport activities, conditioning activities, leisure activities, occupational and volunteer activities) including 28 items were questioned in the TWPAS. Participants were first asked if they participated in these categories of activity (yes/no), and if yes answered the questions regarding the average number of days per week and time per day engaged in these activities. If appropriate, questions also differentiated the intensity of activities as light, moderate and vigorous.

The sum of minutes spent in all activity types was multiplied by the metabolic equivalent (MET) level.¹⁴ Summary measures include total minutes/day and total MET-min/day for nine physical activity categories and three intensity levels (light, moderate and vigorous).¹⁵ After reviewing the patterns of response for physical activity categories, two variables were derived: intentional exercise and total moderate and vigorous physical activity. Intentional exercise was the sum of activities that were consciously done for exercising such as sports/dancing, conditioning activities and walking regardless of the intensity level; moderate and vigorous physical activity was the sum of all moderate and vigorous activities including occupational activities. Moderate and vigorous intensity levels of physical activity were combined as one variable because 69% of the participants reported zero vigorous physical activity; 35% of the overall moderate and vigorous physical activity metabolic minutes were the result of intentional exercise. For reference, 188 MET-min/day is equivalent to approximately 1 h of walking or 30 minutes of moderate conditioning exercise such as aerobics and 745 MET-min/day is equivalent to approximately 2.3 h of moderate conditioning exercise.

Cardiac MRI

MRI examinations were performed with 1.5 T magnets (Signa LX or CVi; GE Medical Systems, Waukesha, Wisconsin, USA; Somatom Vision or Sonata; Siemens Medical Systems, Erlangen, Germany) using a four element phased-array surface coil at the same time at which other data were collected. Images were obtained according to a standard protocol.¹⁶ Left ventricular mass and volumes and functional parameters were determined from short axis cine images covering the heart from base to apex throughout the cardiac cycle with temporal resolution less than or equal to 50 ms.

All MRI images were analysed using MASS software (version 4.2) at a single reading centre by readers who had no knowledge of risk factor information. For MRI measurements, the technical error of measurement percentage of the mean was 6% and 4% for left ventricular mass and volume, respectively.¹⁶

Statistical analysis

Characteristics of the study group are presented as mean (SD) for continuous variables and as percentages for categorical variables. Physical activity was examined both in categories and as a continuous predictor. A substantial number of participants (22%) reported no intentional exercise. We therefore selected cut-points that approximately divided participants into quintiles as 0, 1–89, 90–187, 188–364 and greater than 364 MET-min/day for intentional exercise. Quintiles for moderate and vigorous physical activity were 0–239, 240–455, 456–744, 745–1254 and greater than 1254 MET-min/day.

Associations of body surface area (BSA)-indexed left ventricular parameters and heart rate with intentional exercise and moderate and vigorous physical activity were assessed using multivariable regression models. Model 1 was adjusted for age, gender and race/ethnicity; model 2 was further adjusted for systolic blood pressure, diabetes, HDL, LDL levels, smoking status, lipid-lowering and antihypertensive medication use. The results of both models showed the same trends but with diminished magnitude for the fully adjusted model. As there was a significant interaction between gender and physical activity variables; models were stratified by gender instead of adjustment. To explore the relationship between body size and heart size, we also developed separate models including non-indexed cardiac parameters (without BSA) as well as non-indexed cardiac parameters adjusted for height and weight. The results of all models were qualitatively similar, thus we present only the gender-stratified fully adjusted models with BSA-adjusted cardiac indices. The non-linearity of associations in model 2 was explored using generalised additive models. Standardised units were obtained by dividing the mean values of each left ventricular parameter by its standard deviation to present different measures in the same scale. Interactions between age, race/ethnicity and left ventricular parameters were also explored.

All analyses were done using STATA 10 software. *p* Values of less than 0.05 are considered statistically significant and are presented for descriptive purposes. Confidence intervals (CI) are expressed at the 95th percentile.

Results

Subject characteristics

Of the MESA study sample (6814), 5098 underwent cardiac MRI and 5004 participants had technically adequate data. We excluded 12 participants who did not fill out the TWPAS or completed the survey but reported no physical activity, leaving 4992 participants in the analysis. The mean age of included participants was 62 years (range 45–84): 52% were

women, 39% were white, 26% were African-American, 22% were Hispanic and 13% were Chinese American.

The characteristics of the study group by gender are shown in table 1. Compared with men, women were more likely to have hypertension ($p = 0.047$) and had a higher body mass index ($p < 0.001$). Women were less likely to have diabetes ($p < 0.001$) and be smokers ($p < 0.001$). The percentage of participants with hypertension, diabetes and smoking history were 2.7%, 1% and 1% lower than the full MESA cohort, respectively (not shown).

Overall, men had significantly higher indexed left ventricular mass, end-diastolic volume, stroke volume and cardiac output but had lower ejection fraction than women. Levels of daily intentional exercise and moderate and vigorous physical activity were also higher for men than women.

Left ventricular size and function in relation to intentional exercise

Left ventricular mass and end-diastolic volume were positively associated with intentional exercise in a non-linear fashion for both genders (test for non-linearity: left ventricular mass, $p = 0.02$; left ventricular end-diastolic volume, $p = 0.03$). The rate of increase in left ventricular mass and end-diastolic volume in relation to exercise was higher at lower levels of exercise, with a plateau as exercise levels increased (fig 1A). Because left ventricular mass and end-diastolic volume increased proportionally, the ratio of mass to volume (a measure of myocardial remodelling) showed no significant change with increasing intentional exercise for both genders (table 2). For men in the highest category of intentional exercise, the mean left ventricular mass and left ventricular end-diastolic volume were 3.10 g/m^2 (95% CI 1.22 to 4.98) and 4.18 ml/m^2 (95% CI 2.38 to 5.98) greater than men reporting no intentional exercise. Associations showed similar trends for women but with diminished magnitude (table 2).

Left ventricular end-systolic volume also increased with intentional exercise but at a smaller rate than left ventricular end-diastolic volume; therefore stroke volume was positively associated with intentional exercise for both genders (fig 1B). As was the case for left ventricular mass and volumes, the increase in stroke volume with exercise was greater at lower levels of exercise. In the highest category of intentional exercise, the mean increase in stroke volume was 2.50 ml/m^2 (95% CI 1.33 to 3.68) for men and 1.06 ml/m^2 (95% CI 0.06 to 2.05) for women compared with participants reporting no intentional exercise (table 2).

Cardiac output and ejection fraction did not significantly change with increasing exercise levels for both genders (table 2). However, resting heart rate decreased with increasing intentional exercise (fig 1C). The decreased heart rate was consistent with increased stroke volume but nearly unchanged cardiac output in relation to exercise. The change in heart rate was greater at lower exercise levels, with a plateau as exercise levels increased (test for non-linearity, $p < 0.001$).

A high percentage of individuals in this study had hypertension (44% of women, 41% of men). As expected, hypertensive participants had higher left ventricular mass, lower end-systolic volume at baseline compared with participants without hypertension. Similar to normotensive participants, the left ventricular mass to volume ratio was unchanged with increasing levels of exercise in the hypertensive subgroup (not shown).

Evaluation of age, left ventricular size and function with exercise

When participants were stratified by gender and age (by decade), increased age was associated with higher levels of left ventricular mass to volume ratio for both men and women (fig 2) indicating age-related adverse myocardial remodelling. There was very little

change in myocardial remodelling with higher levels of physical activity across all age categories.

The myocardial response to exercise and physical activity was similar for all ethnic groups without statistically significant differences (not shown).

Left ventricular size and function in relation to moderate and vigorous physical activity

Moderate and vigorous physical activity showed similar patterns in associations for all left ventricular parameters. Although the trend of associations was similar for both genders, the magnitude was diminished and not statistically significant for women (data are shown in appendix 1 table 1).

Discussion

In this study, we evaluated the relationship between physical activity and myocardial size and function in a non-athletic population that was ethnically diverse and free from clinically apparent cardiovascular disease at baseline. There are several conclusions: (1) Higher physical activity levels were associated with greater left ventricular mass and volume. However, the left ventricular mass to volume ratio, a measure of cardiac remodelling, was unchanged over different exercise categories, indicating proportional increases in left ventricular mass and volume with physical activity. (2) Global ventricular systolic function measured by ejection fraction was unchanged with higher physical activity levels despite the alterations in left ventricular size. (3) Physical activity showed a stronger relationship to heart size and function in men compared with women. (4) The associations of physical activity with left ventricular remodelling were consistent over all age groups.

Studies of cardiac morphology in athletes compared with control subjects have demonstrated significant myocardial adaptation to increased haemodynamic load. This has been described as the athlete's heart. In almost all studies, endurance training was found to be associated with proportional increases in left ventricular wall thickness and cavity dimensions (eccentric hypertrophy).^{4 17 18} The modality, intensity, duration and frequency of exercise, as well as body size, gender and genetic determinants influence the grade of cardiac adaptations.¹⁸ However, most myocardial changes with exercise fall within normal ranges.³ ¹⁹ Left ventricular systolic function measured by ejection fraction is usually normal in the athlete's heart, suggesting a physiological rather than a pathological myocardial response.^{5 20} Besides studies of trained athletes, previous population-based studies examining the association of left ventricular mass with leisure time physical activity also reported a slight increase in left ventricular mass in men under the age of 50 years; this relationship was not observed in women or older men.^{6 7} One of the limitations of these previous studies was accounting for only leisure time activities but not occupational activities. We sought to assess the impact of both leisure and occupational activities on the heart by using intentional exercise and moderate and vigorous physical activity variables. Associations for both parameters showed similar relationships but with diminished magnitude in women compared with men.

The non-linearity of relationships between exercise and left ventricular mass and volumes was expressed by a steeper slope at lower levels of exercise and a plateau at higher levels of exercise. This has not previously been described. One previous study reported a dose-response relationship between physical activity and the risk of coronary heart disease at least up to a certain level of activity.²¹ The non-linear relationship observed in this study suggests that a beneficial cardiac response to increased exercise may be possible even in the lowest categories of physical activity with a lesser response at high levels of exercise. The cause of this non-linearity is unknown. It is interesting to note that even infrequent intense physical

activity is associated with a reduced risk of premature death in the recent physical activity guidelines of the US Department of Health and Human Services.¹ The extent to which any survival benefit from exercise is mediated through myocardial remodelling is not elucidated in this cross-sectional study. However, the beneficial cardiac remodelling associated with physical activity that we observed further supports recommendations for physical activity for individuals without a history of cardiovascular events.

The reasons for gender differences in response to physical activity are unknown. Changes in cardiac muscle mass may reflect overall reduced muscle mass in women compared with men. We observed higher physical activity and exercise levels for men compared with women, perhaps reducing the effect sizes in women. Another factor may be different sensitivities to preload/afterload between the genders. Rosen *et al*²² showed a significant gender difference in adaptation to chronic states of increased afterload in the MESA population. A similar scenario may be true for increased afterload transiently induced by exercise or physical activity. For both hypertensive men and women, we also observed the same pattern of myocardial remodelling in response to exercise and physical activity as non-hypertensive participants. These results may support the favourable impact of physical activity to decelerate or reverse the concentric pattern of left ventricular remodelling in hypertensive individuals regardless of gender.

Physiological ageing has been shown to be associated with smaller heart size. The smaller and stiffer heart in older individuals shows an increase in the ratio of left ventricular mass to volume (fig 2).²³ It is unclear to what extent these ageing adaptations are due to a sedentary lifestyle or if these changes could be modified with exercise.²⁴ This study was not able to show a significant change in the reversal of age-related adverse myocardial remodelling with increasing physical activity. This may be because of a small sample size in each age category and low physical activity levels in older ages.

The use of cardiac MRI in this study may bring an additional insight into the pattern of left ventricular remodelling as a highly accurate and reproducible technique for defining ventricular geometry and function. Unlike echocardiography, MRI defines the changes in left ventricular mass and volume in the same time with left ventricular mass to volume ratio. Several studies investigated the impact of endurance training on cardiac morphology with MRI and confirmed previous echocardiography findings.^{25–30} The left ventricular mass to volume ratio was reported as either unchanged²⁷ or increased²⁶ compared with controls.

Strengths and limitations

The present study is the first to investigate the relationship of left ventricular mass, volumes and function to physical activity in a large multiethnic population free of clinically apparent cardiovascular disease at baseline. The selection of participants in MESA was designed to minimise biases typically associated with studies of volunteers. However, they do not represent a random sample of the US population. As all of our participants were free of clinically apparent cardiovascular disease at baseline, participants represent a relatively healthy population-based sample whose physical activity capacity may be better than that of elderly individuals in the general population. The daily physical activity levels of participants were estimated by a semiquantitative questionnaire that may reflect only an approximate amount rather than absolute physical activity values. The relevant time period for physiological cardiac remodelling is not fully defined in our study. Finally, smaller sample sizes for some ethnicities may have limited our ability to detect ethnic interactions.

Conclusions

In a community-based population, physical activity was associated with physiological left ventricular remodelling, marked by proportionally greater left ventricular mass and end-diastolic volume and unchanged left ventricular mass to volume ratio. The magnitude of associations was diminished for women compared with men but trends were similar across individuals of both genders.

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Appendix 1

Table 1
Mean differences in left ventricular measures and resting heart rate associated with moderate and vigorous physical activity for women and men after adjustment for risk factors

Moderate and vigorous physical activity (MET-min/day)	LV ED mass, g/m ² (95% CI)	LV ED volume, ml/m ² (95% CI)	LV ES volume, ml/m ² (95% CI)	LV stroke volume, ml/m ² (95% CI)	LV cardiac output, l/min/m ² (95% CI)	LV ejection fraction, % (95% CI)	LV mass/volume ratio (95% CI)	Resting heart rate, bpm (95% CI)
Women								
0–240	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
240–456 [§] Estimate*	−0.29 (−1.65 to 1.07)	0.60 (−0.69 to 1.89)	0.22 (−0.49 to 0.93)	0.38 (−0.56 to 1.32)	0.02 (−0.06 to 0.10)	−0.02 (−0.78 to 0.74)	−0.02 (−0.04 to 0.01)	−0.11 (−1.48 to 1.26)
456–745 [¶] Estimate	0.36 (−1.00 to 1.72)	0.75 (−0.54 to 2.04)	0.01 (−0.70 to 0.72)	0.74 (−0.20 to 1.68)	−0.03 (−0.11 to 0.05)	0.21 (−0.55 to 0.98)	−0.01 (−0.03 to 0.02)	−1.81 (−3.17 to 1.25)
745–1254 ^{**} Estimate	0.91 (−0.49 to 2.30)	0.73 (−0.60 to 2.05)	0.28 (−0.45 to 1.01)	0.45 (−0.52 to 1.42)	−0.01 (−0.09 to 0.08)	−0.24 (−1.02 to 0.54)	−0.00 (−0.03 to 0.02)	−0.88 (−2.29 to 0.52)
>1254 Estimate	1.00 (−0.48 to 2.47)	1.04 (−0.36 to 2.44)	0.30 (−0.47 to 1.08)	0.74 (−0.29 to 1.76)	−0.02 (−0.11 to 0.07)	−0.21 (−1.04 to 0.61)	−0.00 (−0.03 to 0.02)	−1.83 [‡] (−3.32 to −0.35)
Men								
0–240	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
240–456 [§] Estimate*	2.46 [‡] (0.47 to 4.45)	1.64 (−0.28 to 3.56)	0.21 (−0.94 to 1.37)	1.43 [‡] (0.17 to 2.68)	0.08 (−0.02 to 0.18)	0.44 (−0.52 to 1.40)	0.00 (−0.03 to 0.04)	−0.35 (−1.89 to 1.19)
456–745 [¶] Estimate	3.91 [‡] (1.90 to 5.92)	1.99 [‡] (0.06 to 3.92)	1.01 (−0.15 to 2.18)	0.98 (−0.28 to 2.24)	0.04 (−0.05 to 0.14)	−0.53 (−1.50 to 0.44)	0.02 (−0.02 to 0.05)	−0.30 (−1.85 to 1.25)
745–1254 ^{**} Estimate	4.01 [‡] (2.03 to 5.99)	2.62 [‡] (0.71 to 4.52)	1.18 [‡] (0.03 to 2.33)	1.44 [‡] (0.19 to 2.68)	0.06 (−0.03 to 0.16)	−0.61 (−1.57 to 0.35)	0.01 (−0.02 to 0.05)	−0.85 (−2.37 to 0.68)
>1254 Estimate	6.37 [‡] (4.42 to 8.31)	4.20 [‡] (2.33 to 6.07)	1.30 [‡] (0.17 to 2.43)	2.90 [‡] (1.68 to 4.13)	0.12 (0.02 to 0.21)	−0.04 (−0.98 to 0.90)	0.01 (−0.02 to 0.05)	−1.73 [‡] (−3.23 to −0.23)

* Coefficients represent change in left ventricular (LV) measures across moderate and vigorous physical activity categories, having the 0–240 metabolic equivalent minutes per day (MET-min/day) physical activity as reference. Left ventricular parameters were indexed to body surface area except ejection fraction and mass/volume ratio. All models were adjusted for age, race/ethnicity, systolic blood pressure, hypertension medication use, diabetes status, total cholesterol, high-density lipoprotein, lipid-lowering medication use and smoking status.

[†] $p \leq 0.05$;

[‡] $p \leq 0.001$.

[§] Four hundred and fifty-six MET-min/day is equivalent to approximately 1.4 h of moderate conditioning exercise.

[¶] Seven hundred and forty-five MET-min/day is equivalent to approximately 2.3 h of moderate conditioning exercise.

^{**} One thousand two hundred and fifty-four MET-min/day is equivalent to approximately 3.8 h of moderate conditioning exercise. bpm, beats per minute; ED, end-diastolic; ES, end-systolic.

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Figure 1.

Generalised additive models representing associations of left ventricular end-diastolic mass (EDM), end-diastolic volume (EDV) (A), stroke volume (SV) (B) and resting heart rate (C) with intentional exercise after adjustment for risk factors. *Models are stratified by gender and adjusted for age, race/ethnicity, systolic blood pressure, hypertension medication use, diabetes status, total cholesterol, high-density lipoprotein, lipid-lowering medication use and smoking status.

Figure 2.

Age-stratified generalised additive models showing the association of mass/volume ratio with intentional exercise after adjustment for risk factors for men (A) and women (B).

*Models are stratified by gender and age and fully adjusted as in fig 1. MET, metabolic equivalent.

Table 1
Gender-stratified characteristics among MESA participants, 2000–2

Characteristics	Women	Men
	N = 2614	N = 2378
	Mean (SD) or n (%)	Mean (SD) or n (%)
Risk factors		
Hypertension	1139 (44%)	970 (41%) [†]
SBP, mm Hg	125.7 (23.0)	125.2 (19.3)
Hypertension medication use	954 (37%)	803 (34%) [†]
Diabetes	271 (10%)	309 (13%) [†]
LDL-cholesterol, mg/dl	117.4 (31.7)	117.0 (30.8)
HDL-cholesterol, mg/dl	56.8 (15.5)	45.0 (11.6) [†]
Lipid-lowering medication use	431 (17%)	364 (15%)
Ever smoker	1043 (40%)	1377 (58%) [†]
Body mass index, kg/m ²	28.0 (5.6)	27.4 (4.1) [†]
Height, cm	160 ± 7.1	173 ± 7.7 [†]
Absolute LV size and function measures		
LV end-diastolic mass, g	123.8 (27.4)	168.9 (37.2) [†]
LV end-diastolic volume, ml	113.8 (24.4)	140.2 (32.7) [†]
LV end-systolic volume, ml	33.1 (12.0)	47.6 (18.6) [†]
LV ejection fraction, %	71.3 (6.6)	66.6 (7.5) [†]
LV stroke volume, ml	80.7 (17.0)	92.6 (20.8) [†]
Cardiac output, l/minute	5.4 (1.4)	6.0 (1.5) [†]
LV mass/volume ratio	1.1 (0.2)	1.2 (0.3) [†]
BSA-indexed LV size and function measures		
LV end-diastolic mass, g/m ²	70.8 (12.6)	85.8 (16.3) [†]
LV end-diastolic volume, ml/m ²	65.2 (11.3)	71.3 (15.1) [†]
LV end-systolic volume, ml/m ²	18.9 (6.2)	24.1 (9.0) [†]
LV stroke volume, ml/m ²	46.3 (8.2)	47.2 (9.8) [†]
Cardiac output, l/minute per m ²	3.1 (0.71)	3.0 (0.8) [†]
Physical activity measures*		
Moderate physical activity	199.9 (182.1)	206.0 (193.9)
Vigorous physical activity [§]	19.7 (70.9)	62.8 (153.7) [†]
Moderate and vigorous physical activity	752.7 (718.4)	921.8 (971.5) [†]
Intentional exercise [¶]	201.3 (292.3)	258.8 (380.0) [†]

* Physical activity levels were assessed as metabolic equivalent minutes per day (MET-min/day).

[†] p ≤ 0.05;

[‡] $p \leq 0.001$.

[§]Seventy-eight per cent of women and 56% of men reported zero vigorous physical activity.

[¶]Twenty-three per cent of women and 20% of men reported zero intentional exercise. BSA, body surface area; HDL, high-density lipoprotein; LDL, low-density lipoprotein; LV, left ventricular; MESA, Multiethnic Study of Atherosclerosis; SBP, systolic blood pressure.

Table 2
Mean differences in left ventricular measures and resting heart rate associated with intentional exercise for women and men after adjustment for risk factors

Intentional exercise, MET-min/day	LV ED mass, g/ m ² (95% CI)	LV ED volume, ml/m ² (95% CI)	LV ES volume, ml/m ² (95% CI)	LV stroke volume, ml/m ² (95% CI)	LV cardiac output, l/min/ m ² (95% CI)	LV ejection fraction, % (95% CI)	LV mass/volume ratio (95% CI)	Resting heart rate, bpm (95% CI)
Women								
0	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
0-90 [§] Estimate*	-0.59 (-1.88, 0.71)	-0.04 (-1.27 to 1.19)	0.09 (-0.59 to 0.77)	-0.13 (-1.03 to 0.77)	-0.04 (-0.12 to 0.04)	-0.11 (-0.83 to 0.62)	-0.01 (-0.03 to 0.01)	-0.67 (-1.97 to 0.63)
90-188 [¶] Estimate	1.34 (-0.04 to 2.72)	1.05 (-0.26 to 2.36)	0.46 (-0.27 to 1.18)	0.59 (-0.36 to 1.55)	-0.05 (-0.13 to 0.03)	-0.19 (-0.96 to 0.59)	0.00 (-0.02 to 0.02)	-1.94 [‡] (-3.32 to -0.55)
188-364 ^{**} Estimate	1.61 [‡] (0.24 to 2.99)	1.83 [‡] (0.53 to 3.13)	0.43 (-0.29 to 1.15)	1.40 [‡] (0.45 to 2.35)	-0.05 (-0.13 to 0.03)	0.15 (-0.62 to 0.92)	-0.01 (-0.03 to 0.01)	-3.23 [‡] (-4.61 to -1.84)
>364 Estimate	1.42 [‡] (-0.02, 2.86)	1.67 [‡] (0.30 to 3.03)	0.61 (-0.15 to 1.36)	1.06 [‡] (0.06 to 2.05)	-0.04 (-0.13 to 0.05)	-0.27 (-1.08 to 0.53)	-0.01 (-0.03 to 0.01)	-2.62 [‡] (-4.07 to -1.18)
Men								
0	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
0-90 1 Estimate*	-0.34 (-2.31 to 1.63)	1.43 (-0.46 to 3.31)	1.09 (-0.05 to 2.22)	0.34 (-0.89 to 1.58)	-0.03 (-0.13 to 0.07)	-0.62 (-1.56 to 0.33)	-0.04 [‡] (-0.07 to -0.00)	-1.46 (-2.97 to 0.04)
90-188 2 Estimate	0.36 (-1.62 to 2.34)	1.27 (-0.62 to 3.17)	0.65 (-0.50 to 1.79)	0.63 (-0.62 to 1.87)	0.07 (-0.02 to 0.17)	-0.27 (-1.23 to 0.68)	-0.03 (-0.06 to 0.01)	0.51 (-1.00 to 2.03)
188-364 3 Estimate	0.51 (-1.44 to 2.45)	2.54 [‡] (0.68 to 4.41)	1.00 [‡] (-0.12 to 2.12)	1.54 (0.32 to 2.76)	0.06 (-0.04 to 0.15)	-0.20 (-1.13 to 0.74)	-0.04 [‡] (-0.07 to -0.01)	-1.08 (-2.57 to 0.41)
>364 Estimate	3.10 [‡] (1.22 to 4.98)	4.18 [‡] (2.38 to 5.98)	1.68 (0.59 to 2.76)	2.50 [‡] (1.33 to 3.68)	0.05 (-0.04 to 0.14)	-0.38 (-1.28 to 0.53)	-0.03 (-0.06 to 0.00)	-2.61 [‡] (-4.05 to -1.18)

* Coefficients represent change in left ventricular (LV) measures across intentional exercise categories, having the 0 metabolic equivalent minutes per day (MET-min/day) exercise as reference. Left ventricular parameters were indexed to body surface area except ejection fraction and mass/volume ratio. All models were adjusted for age, race/ethnicity, systolic blood pressure, hypertension medication use, diabetes status, total cholesterol, high-density lipoprotein, lipid-lowering medication use and smoking status.

[‡] p ≤ 0.05;

[‡] p ≤ 0.001.

[§] Ninety MET-min/day is equivalent to approximately 30 minutes of walking or 15 minutes of moderate conditioning exercise such as aerobics.

[¶] One hundred and eighty-eight MET-min/day is equivalent to approximately 1 h of walking or 30 minutes of moderate conditioning exercise such as aerobics.

*** Three hundred and sixty-four MET-min/day is equivalent to approximately 2 h of walking or 1 h of moderate conditioning exercise such as aerobics. bpm, beats per minute; ED, end-diastolic; ES, end-systolic.