

# Association of Socioeconomic Status With Functional Capacity, Heart Rate Recovery, and All-Cause Mortality

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LOWER SOCIOECONOMIC STATUS (SES) is associated with all-cause as well as cardiovascular morbidity and mortality.<sup>1-9</sup> The biological and behavioral mediators underlying this association are uncertain.<sup>5,10-15</sup> Previous work suggests that individuals with lower SES may have fewer options for safe outdoor exercise, purchase less healthy foods, and have greater exposure to tobacco vendors and tobacco-related public advertisements.<sup>16-19</sup> These characteristics have the potential to contribute to impaired functional capacity and autonomic dysfunction, both of known prognostic importance.<sup>1,20-23</sup> We hypothesized that functional capacity and heart rate recovery, a measure of autonomic function, are associated with lower SES and may account for a portion of the SES mortality differential.

## METHODS

### Study Design

Study participants were consecutive patients who came from 7 adjacent counties in northeast Ohio (Cuyahoga, Lake, Geauga, Portage, Lorain, Medina, and Summit) and were referred for symptom-limited treadmill exercise testing at the Cleveland Clinic from 1990 to 2002, for evaluation of known or sus-

**Context** Lower socioeconomic status (SES) confers heightened cardiovascular risk and mortality, although the mediating pathways are unclear.

**Objective** To evaluate the extent to which exercise physiologic characteristics account for the association between lower SES and mortality.

**Design, Setting, and Participants** Prospective cohort study of 30 043 consecutive patients living in 7 counties in northeast Ohio referred between 1990 and 2002 for symptom-limited stress testing for evaluation of known or suspected coronary artery disease. Follow-up for mortality continued through February 2004.

**Main Outcome Measures** Estimated functional capacity in metabolic equivalents and heart rate recovery, physiologic characteristics that are determined directly from exercise; testing and all-cause mortality during a median follow-up of 6.5 years.

**Results** Multivariable models adjusting for demographics, insurance status, smoking status, and clinical confounders demonstrated a strong association between a composite SES score based on census block data and functional capacity (adjusted odds ratio comparing 25th with 75th percentile values, 1.72; 95% confidence interval [CI], 1.56-1.89;  $P < .001$ ) as well as heart rate recovery (adjusted odds ratio comparing 25th with 75th percentile values, 1.18; 95% CI, 1.07-1.30;  $P < .001$ ). There were 2174 deaths, with mortality risk increasing from 5% to 10% as SES decreased by quartile ( $P < .001$ ). Cox proportional hazards models that included all confounding variables except exercise physiologic characteristics demonstrated increased mortality as SES decreased (adjusted hazard ratio comparing 25th with 75th percentile values, 1.32; 95% CI, 1.22-1.42;  $P < .001$ ). After further adding functional capacity and heart rate recovery, the magnitude of this relationship was reduced (comparing 25th with 75th percentile values; adjusted hazard ratio, 1.17; 95% CI, 1.08-1.26;  $P < .001$ ), with these variables explaining 47% of the association.

**Conclusions** Impaired functional capacity and abnormal heart rate recovery were strongly associated with lower SES and accounted for a major proportion of the correlation between SES and mortality. Efforts to modify these clinical features among patients with low SES may narrow disparities in mortality.

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pected coronary artery disease. The Cleveland Clinic and its regional practice satellites are a closed institution; only physicians employed by the clinic can refer patients for stress testing. Patients were excluded if they lacked a valid address or a US Social Security number. Other exclusions were end-

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stage renal disease, prior pacemaker implantation, symptomatic heart failure, atrial fibrillation, organ transplantation, or use of digoxin. If patients had more than 1 stress study performed, only the first was included. The institutional review board of the Cleveland Clinic approved this study, and the requirement for written informed consent was waived.

Before testing, patients underwent a detailed interview and chart review regarding home address, cardiovascular risk factors, history, symptoms, previous cardiac procedures, other medical diagnoses, and medication use as previously described.<sup>24</sup> Race and ethnicity were based on self-report. During each stage of testing, we noted heart rate, blood pressure, electrocardiographic changes, symptoms, and arrhythmias. All clinical and exercise data were recorded prospectively online as part of routine clinical reporting.

### Exercise Variables

Functional capacity in metabolic equivalents (estimated exercise capacity where 1 metabolic equivalent = 3.5 mL/kg/min of oxygen consumption) was considered impaired if it fell in the lowest quartile for each sex and decade of age (eg, men aged 40-49 years, women aged 40-49 years). Heart rate recovery was considered abnormal if after 1 minute following peak exercise, the heart rate did not fall by more than 12/min; among patients undergoing stress echocardiography, the cutoff value was more than 18/min.<sup>25-27</sup> Individuals responsible for conducting each test and obtaining baseline and exercise variables were blinded to study objectives and subsequent outcomes.

### SES Score

Information regarding SES was primarily assessed by matching each patient's home address to his/her census block, a geographical unit containing approximately 1000 residents, as obtained from the 2000 US Census.<sup>28</sup> We used a previously validated approach to calculate a composite SES score using 6 census block characteristics (me-

dian household income; median value of housing unit; proportion of households receiving interest, dividend, or net rental income; the proportion of adults aged 25 years or older who had completed high school; proportion of adults aged 25 years or older who had completed college; and the proportion of employed persons aged 16 years or older in executive, managerial, or professional specialty occupations).<sup>3</sup> Derivation of this score, described in detail elsewhere,<sup>3</sup> involves normalizing each of the 6 components around 0, which represents the average value across all census blocks. Previous work in population-based cohorts demonstrates the value of this score as an independent predictor of cardiovascular risk.<sup>3</sup> To assess the sensitivity of our analyses to the measure of SES used, we also tested models using a composite based on 1990 census data and a simpler measure of poverty: the proportion of residents in each census block with incomes below the federally defined poverty level.<sup>29</sup>

As supplementary measures of SES, we obtained available data on medical insurance, the distance between a patient's home and the clinic, and employment status.

### End Points

The primary end point was all-cause mortality, which we have described previously as an objective, unbiased, and clinically relevant outcome.<sup>30</sup> Mortality was assessed by querying the Social Security Death Index; we and others have previously shown that this approach yields a high sensitivity and specificity for classifying deaths.<sup>26,31</sup> The censoring date was February 1, 2004.

### Statistical Analysis

For descriptive purposes, the distribution of SES scores was divided into quartiles. Multivariable logistic regression models assessed the association between SES score, considered as a continuous variable, and both impaired functional capacity and abnormal heart rate recovery, adjusting for sex, race, type of medical insurance, current smoking status,

diagnosis of hypertension, type 1 and 2 diabetes mellitus, history of myocardial infarction, coronary artery bypass graft surgery, percutaneous coronary intervention, cerebrovascular accident, peripheral vascular disease, and current use of aspirin,  $\beta$ -blockers, angiotensin-converting enzyme inhibitors, or lipid-lowering medications. We also adjusted for age, body mass index (calculated as weight in kilograms divided by the square of height in meters), resting heart rate, and blood pressure, all as continuous variables. To account for differences in patients' ability to obtain medical evaluation at our health care facility, we calculated the lineal distance from individual's home to the Cleveland Clinic using Arc View geographic information software system version 3.0 (ESRI, Redlands, Calif).

Smooth curvilinear models were fit for continuous variables using restricted cubic natural splines.<sup>32</sup> Bootstrapping was used to account for clustering within each census block using the bootcov function of Harrell's Design library<sup>32</sup>; results were confirmed by frailty analyses.<sup>33</sup> Interaction terms between functional capacity and age, race, smoking status, and body mass index were tested based on prior observations and potential mechanistic links.<sup>34,35</sup> Additional bootstrapping procedures calculated a concordance statistic to assess model discrimination and to generate plots of observed vs predicted values as a measure of model calibration. Bootstrapping allowed for formal assessment of possible overfitting, which for all models turned out to be trivial; the reported *c*-statistics have been "optimism corrected," meaning that they were penalized for any overfitting. Absence of collinearity was ensured by calculation of variance inflation factors.

An association between SES score and all-cause mortality was confirmed using Kaplan-Meier curves and Cox proportional hazards modeling adjusting for baseline variables, revascularization within 90 days of testing, functional capacity, and heart rate recovery. Again, restricted cubic splines were ap-

**Table 1.** Census Block and Patient Characteristics at Time of Stress Testing by Quartiles of SES Score

Characteristics	Quartile, SES Range			
	1 -14.93 to -0.17 (n = 7513)	2 -0.17 to 4.02 (n = 7501)	3 4.02 to 7.68 (n = 7566)	4 7.68 to 17.61 (n = 7463)
Census block characteristics, mean (SD)				
Composite socioeconomic score	-4.2 (3)	1.9 (1)	5.6 (1)	10 (2)
Median household income, \$ in thousands	31.2 (10.2)	47.9 (9.2)	62.3 (11.8)	94.7 (30.2)
Median value of housing units, \$ in thousands	77.8 (23.3)	129.0 (24.6)	170.0 (37.5)	262.0 (95.5)
Households with interest, dividend, or rental income, %	22 (12)	45 (9)	55 (8)	68 (7)
Adult residents who completed high school, %	73 (11)	87 (4)	92 (3)	96 (3)
Adult residents who completed college, %	10 (6)	25 (9)	39 (9)	61 (11)
Employed residents with executive, managerial, or professional occupations, %	22 (8)	35 (7)	46 (7)	61 (8)
Individuals below poverty level, median (range), %	15 (0-75)	4 (0-37)	2 (0-54)	2 (0-24)
Employment status (if known), No. (%)				
Employed	3103 (41)	3242 (43)	3651 (48)	4081 (55)
Unemployed	762 (10)	575 (8)	475 (6)	390 (5)
Retired	2215 (29)	2383 (32)	2148 (28)	1706 (23)
Demographic characteristic				
Age, mean (SD), y	55 (13)	56 (13)	55 (12)	54 (11)
Male sex, No. (%)	4174 (56)	4855 (65)	5211 (69)	5498 (74)
Black race, No. (%)	3625 (48)	566 (8)	437 (6)	279 (4)
Asian race, No. (%)	37 (0.5)	57 (1)	105 (1)	118 (2)
Hispanic, No. (%)	99 (1)	25 (<1)	15 (<1)	3 (<1)
Body mass index*	30 (6)	28 (5)	28 (5)	27 (4)
Distance from patient's house to hospital, mean (SD), km	14.4 (14.4)	25.6 (14.4)	24 (11.2)	20.8 (9.6)
Insurance status (if known), No. (%)				
Medicaid	345 (5)	73 (1)	44 (1)	18 (0.2)
Medicare	1415 (19)	1414 (19)	1071 (14)	823 (11)
Commercial fee-for-service and managed care	3482 (46)	3858 (51)	4019 (53)	4019 (54)
Clinical history, No. (%)				
Diabetes, type 1	513 (7)	246 (3)	172 (2)	129 (2)
Diabetes, type 2	858 (11)	638 (8)	502 (7)	316 (4)
Hypertension	4838 (64)	4371 (58)	4073 (54)	3259 (44)
Current smoker	2189 (29)	1467 (20)	1170 (15)	805 (11)
Family history of heart disease	2364 (31)	2556 (34)	2429 (32)	2202 (30)
Known coronary artery disease	1649 (22)	1881 (25)	1617 (21)	1186 (16)
History of myocardial infarction	1062 (14)	1120 (15)	934 (12)	674 (9)
History of coronary artery bypass graft surgery	789 (10)	1048 (14)	865 (11)	718 (10)
History of percutaneous coronary intervention	885 (12)	955 (13)	944 (12)	651 (9)
History of peripheral vascular disease	204 (3)	179 (2)	125 (2)	80 (1)
History of cerebrovascular accidents	153 (2)	98 (1)	73 (1)	51 (1)
Medication use, No. (%)				
Angiotensin-converting enzyme inhibitor	1152 (15)	912 (12)	817 (11)	620 (8)
Aspirin	2424 (32)	2429 (32)	2135 (28)	1801 (24)
β-Blocker treatment	1617 (22)	1506 (20)	1308 (17)	883 (12)
Lipid-lowering treatment	1173 (16)	1377 (18)	1343 (18)	1117 (15)

Abbreviation: SES, socioeconomic status.

\*Body mass index is calculated as weight in kilograms divided by the square of height in meters.

plied to continuous variables and bootstrapping methods were used to account for clustering within census blocks. The proportional hazards assumption was tested by calculating weighted Schoenfeld residuals and by inspecting hazard ratio (HR) against time plots for selected variables. Good model discrimination was confirmed by concordance statistic for right-censored data of 0.82, while model calibration was assessed by plots of observed vs predicted values derived from 200 bootstrap resamplings.<sup>36</sup>

Since individuals with lower SES may encounter greater barriers in obtaining care despite having characteristics or engaging in behaviors that increase risk for cardiovascular disease, we created a propensity score based on the variables shown in TABLE 1.<sup>6,9,10,37</sup> This score was then used to match individuals with the lowest and highest quartiles of SES score. To further account for the influence of important clinical risk factors, supplemental analyses adjusted for left ventricular ejection fraction, ischemia, and scar in patients who underwent exercise stress echocardiography.

To quantify the relative contribution of functional capacity and heart rate recovery to the observed association between SES and mortality, we used the formula<sup>38</sup>:

$$\left( \frac{HR_{SES} - HR_{SES + \text{functional capacity} + \text{heart rate recovery}}}{HR_{SES} - 1} \right)$$

where HR<sub>SES</sub> represents the hazard ratio for mortality adjusted for all patient characteristics other than functional capacity and heart rate recovery and HR<sub>SES+functional capacity+heart rate recovery</sub> reflects the hazard ratio for mortality including these physiological characteristics.

Analyses were performed using SAS statistical software version 9.1 (SAS Institute Inc, Cary, NC) and S-plus statistical software version 7.0 (Insightful Corp, Seattle, Wash). Multivariable regression models and related diagnostics were assembled using the Design and Hmisc libraries of Harrell. All tests were 2-tailed; P<.05 was considered significant.

## RESULTS

### Baseline Characteristics

Of 2324 residential census blocks in the 7-county area, 2116 (91%) were represented by 30 043 patients in our sample. Most of the patients (17 509 or 58%) were referred by main campus internists or community practitioners at Cleveland Clinic satellites. Within each census block the proportion of black individuals in our sample was similar to the overall block proportion (mean proportional values 0.20 [0.34] for both), but the proportions of men (0.64 [0.23] vs 0.48 [0.06]) and of individuals aged 65 years or older (0.25 [0.22] vs 0.14 [0.09]) were higher in our sample than in the census blocks themselves.

Patients in the lowest quartile of SES score were more likely to be from racial or ethnic minority groups, to have higher body mass index, and to have diabetes, hypertension, or previously documented cardiovascular disease (Table 1). In addition, these individuals lived closer to the main campus, were more likely to be unemployed, more likely to be covered by Medicare and Medicaid, and less likely to have commercial fee-for-service or managed care insurance.

### Exercise Characteristics

The most common clinical indications for exercise testing in the study sample were diagnostic assessment for coronary artery disease (74%) and follow-up for coronary artery disease (18%). Resting hemodynamic and exercise findings according to quartiles of SES score are shown in TABLE 2. As SES score decreased, maximum metabolic equivalents and heart rate recovery also declined.

### Association of Functional Capacity With SES

Impaired functional capacity was more common with lower SES score (Table 2 and TABLE 3, FIGURE 1). After adjusting for multiple potential confounders, this association remained robust (Table 3). Also, in a series of stratified analyses, this association remained consistent among subsets of age, sex, race,

**Table 2.** Exercise and Hemodynamic Measures by Quartiles of SES Score

Characteristics	Quartile, SES Range			
	1 -14.93 to -0.17 (n = 7513)	2 -0.17 to 4.02 (n = 7501)	3 4.02 to 7.68 (n = 7566)	4 7.68 to 17.61 (n = 7463)
Functional capacity, metabolic equivalents*				
Men, mean (SD), y	8.6 (2.4)	9.3 (2.5)	10.0 (2.4)	10.6 (2.6)
Women, mean (SD), y	6.8 (1.9)	7.5 (2.1)	7.9 (2.1)	8.5 (2.1)
Impaired functional capacity, No. (%)	3106 (41)	1887 (25)	1382 (18)	866 (12)
Resting heart rate, mean (SD), beats/min	75 (14)	75 (14)	75 (13)	73 (13)
Peak heart rate, mean (SD), beats/min	152 (22)	155 (22)	158 (21)	162 (20)
Resting blood pressure, mean (SD), mm Hg				
Systolic	134 (21)	134 (20)	133 (20)	130 (19)
Diastolic	86 (12)	86 (11)	86 (11)	85 (11)
Peak systolic blood pressure, mm Hg	188 (29)	187 (27)	187 (27)	187 (27)
Heart rate recovery, mean (SD), beats/min†				
Exercise electrocardiogram/nuclear only	18 (9)	18 (8)	19 (9)	20 (9)
Exercise echocardiography only	30 (12)	30 (12)	31 (11)	33 (12)
Abnormal heart rate recovery, No. (%)	1831 (24)	1560 (21)	1312 (17)	1049 (14)

Abbreviation: SES, socioeconomic status.

\*Metabolic equivalents refer to estimated exercise capacity where 1 metabolic equivalent = 3.5 ml/kg/min of oxygen consumption.

†Heart rate recovery is defined as heart rate at peak exercise minus heart rate at 1 minute into recovery.

type of ordering physician, date of test, selected risk factors, and non-use of  $\beta$ -blockers. Even within the lowest and highest quartiles of SES score, a strong gradient between the score and impaired functional capacity was noted (Table 3). We noted a strong age interaction (Figure 1), whereby the association between SES score and functional capacity weakened as age increased ( $P$  for interaction = .001).

### Association of Heart Rate Recovery With SES

As SES score decreased, the likelihood of an abnormal heart rate recovery increased (Table 2), although to a lesser degree than observed with impaired functional capacity; also, this association was noted in most subgroups (Table 3). We noted no important interactions with factors known to be associated with autonomic disturbance, such as body mass index and smoking (FIGURE 2), but there was an interaction with black race ( $P$  for interaction = .007). The bootstrap  $c$ -statistics for models of functional capacity and

heart rate recovery were 0.81 and 0.72, respectively.

### Association of SES With Mortality

During a median follow-up of 6.5 years, there were 2174 deaths. The proportions of patients who died ranged from 10% among individuals in the lowest quartile of SES score to 5% with the highest SES scores (FIGURE 3). There was a strong association between low SES score and all-cause mortality (unadjusted HR comparing 25th-75th percentile values, 1.51; 95% confidence interval [CI], 1.43-1.60;  $P < .001$ ), which remained statistically significant after adjusting for differences in baseline demographic and clinical characteristics (adjusted HR, 1.32; 95% CI, 1.22-1.42;  $P < .001$ ). Adding functional capacity and heart rate recovery substantially reduced the magnitude of this association (adjusted HR, 1.17; 95% CI, 1.08-1.26;  $P < .001$ ), with these variables explaining 47% of the association ( $[1.32-1.17] \div [1.32-1.00]$ ).

We observed a similar pattern of findings when focusing on the 112 indi-

**Table 3.** Association of SES Score With Impaired Functional Capacity and Abnormal Heart Rate Recovery in Prespecified Subgroups\*

Stratifying Variable	No. (%) With Impaired Functional Capacity	Adjusted Association With Impaired Functional Capacity, OR (95% CI)†	No. (%) With Abnormal Heart Rate Recovery	Adjusted Association With Abnormal Heart Rate Recovery, OR (95% CI)†
All patients (N = 30 043)	7296 (24)	1.72 (1.56-1.89)	5752 (19)	1.18 (1.07-1.30)
Age, y				
<65 (n = 22 845)	5325 (23)‡	1.81 (1.61-2.04)	3289 (14)	1.15 (1.02-1.30)
≥65 (n = 7198)	1971 (27)‡	1.40 (1.19-1.66)	2463 (34)	1.21 (1.04-1.40)
Sex				
Men (n = 19 738)	4665 (24)	1.66 (1.48-1.87)	3705 (19)	1.24 (1.10-1.39)
Women (n = 10 305)	2631 (26)	1.62 (1.37-1.92)	2047 (20)	1.02 (0.86-1.20)
Race				
White (n = 24 677)	4991 (20)	1.60 (1.44-1.77)	4555 (18)	1.15 (1.04-1.27)
Black (n = 4907)	2207 (45)	1.30 (1.07-1.58)	1142 (23)§	1.04 (0.84-1.28)
Ordering department				
Internal medicine (n = 13 171)	2846 (22)	2.28 (1.93-2.70)	2349 (18)	1.38 (1.19-1.61)
Cardiology (n = 10 139)	2828 (28)	1.42 (1.23-1.64)	2232 (22)	1.11 (0.95-1.28)
Regional practice (n = 4338)	891 (21)	1.39 (1.09-1.77)	626 (14)	0.99 (0.77-1.27)
Date of test				
1990-1994 (n = 10 177)	2415 (24)	1.63 (1.38-1.92)	2294 (23)	1.17 (1.01-1.36)
1995-1998 (n = 8936)	2375 (27)	1.69 (1.42-2.02)	1744 (20)	1.09 (0.91-1.30)
1999-2002 (n = 10 930)	2506 (23)	1.77 (1.50-2.09)	1714 (16)	1.28 (1.08-1.52)
Selected risk factors				
Body mass index >30 (n = 9144)	3826 (42)	1.57 (1.35-1.84)	1991 (22)	1.17 (0.99-1.39)
Current smokers (n = 5631)	2117 (38)	1.66 (1.35-2.03)	1304 (23)	0.95 (0.76-1.18)
Type 1 diabetes (n = 1060)	622 (59)	1.68 (1.05-2.69)	419 (40)	1.43 (0.92-2.21)
SES score				
Lowest quartile (n = 7513)	3106 (41)	1.47 (1.24-1.74)	1831 (24)	1.25 (1.04-1.50)
Highest quartile (n = 7463)	866 (12)	1.56 (1.23-1.98)	1049 (14)	1.18 (0.96-1.44)
Sensitivity analyses				
No β-blocker (n = 24 729)	5409 (22)	1.67 (1.50-1.87)	4433 (18)	1.14 (1.02-1.27)
Employment status known (n = 24 731)	6032 (24)	1.81 (1.62-2.01)	4940 (20)	1.18 (1.06-1.30)
Clustered by ordering location (n = 30 043)	7296 (24)	1.70 (1.41-2.05)	5752 (19)	1.18 (1.01-1.37)

Abbreviations: CI, confidence interval; OR, odds ratio; SES, socioeconomic status.

\*SES score along with all other noncategorical covariates were considered as continuous variables with use of restricted cubic splines to account for nonlinearity.

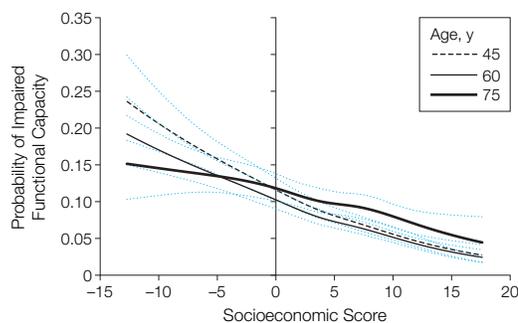
†All odds ratios are adjusted for variables listed in Table 1 (except employment, which was limited to 1 sensitivity analysis). Odds ratios provide effect sizes for a decrease from the 75th percentile value of SES score to the 25th percentile.

‡For impaired functional capacity, there was a significant interaction with age ( $P = .001$ ).

§For abnormal heart rate recovery, there was significant interaction with black race ( $P = .007$ ).

||For model of patients with known employment status, this was added as a categorical confounder.

**Figure 1.** Adjusted Probability of Impaired Functional Capacity According to Socioeconomic Status Score

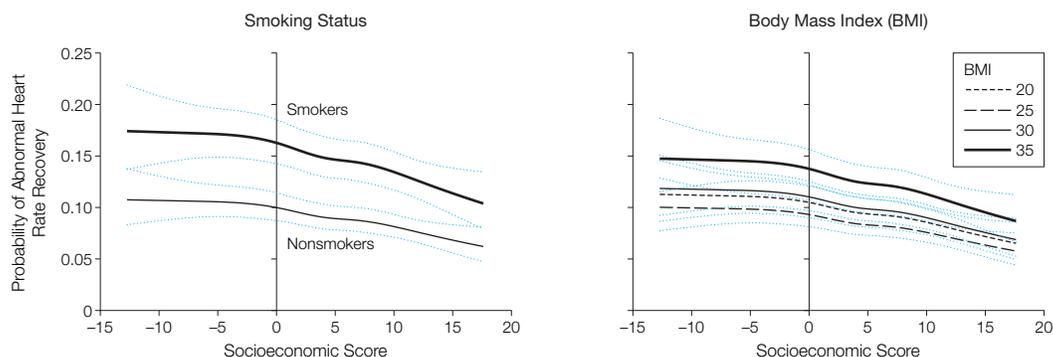


Values are based on logistic regression models. Using the convention of Harrell, continuous variables are set to median values while categorical variables are set to modes. Impaired functional capacity is defined as lowest quartile of metabolic equivalents (1 metabolic equivalent=3.5 mL/kg/min of oxygen consumption) for sex and decades of age. Dotted blue lines indicate 95% confidence intervals.

viduals who died within 6 months of testing. The unadjusted HR relating SES score to 6-month risk of death was 1.32 (95% CI, 1.03-1.69;  $P = .03$ ); addition of clinical variables reduced the statistical significance but not the magnitude of this association (adjusted HR, 1.31; 95% CI, 0.93-1.85;  $P = .12$ ). After adding the exercise variables, the association was markedly attenuated (adjusted HR, 1.05; 95% CI, .74-1.49;  $P = .80$ ).

We noted an interaction between SES score and functional capacity in our model predicting death ( $P$  for interaction = .01), in which the correlation between SES score and death was stronger among individuals with lower

**Figure 2.** Adjusted Probability of Abnormal Heart Rate Recovery According to Socioeconomic Status Score and Body Mass Index



Values are based on logistic regression models. Continuous variables are set to median values while categorical variables are set to modes. Heart rate recovery was considered abnormal if the heart rate failed to fall by more than 12/1 min from peak exercise; this cutoff value was 18/min for patients undergoing exercise stress echocardiography. Body mass index is calculated as weight in kilograms divided by the square of height in meters. Dotted blue lines indicate 95% confidence intervals.

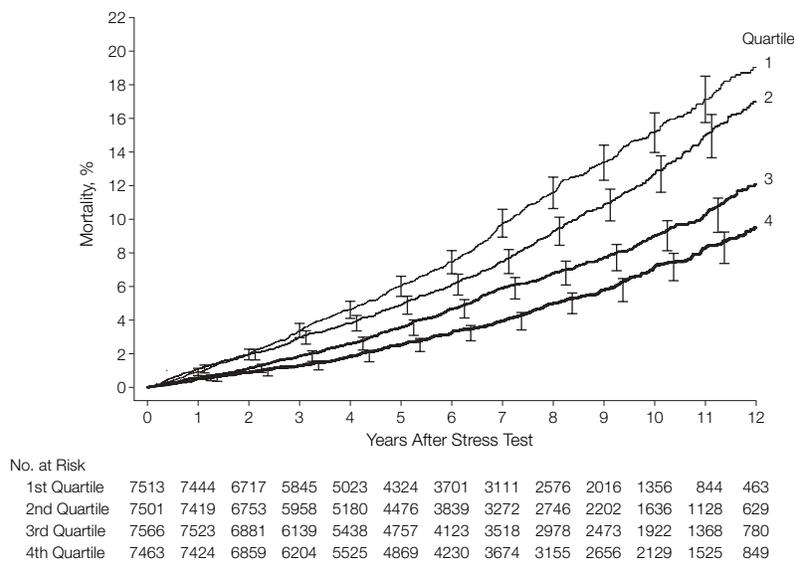
functional capacity than among those with exercise capacity in the highest quartile (FIGURE 4A and Figure 4B). Similarly, age interacted with functional capacity ( $P$  for interaction  $<.001$ ) with a greater association between SES score and mortality among younger individuals (Figure 4A and Figure 4B).

**Propensity Analyses**

We were able to successfully match 3579 patients in the lowest quartile of SES score with 3579 patients in the highest quartile. There was excellent matching for all characteristics listed in Table 1. For example, among patients in the fourth and first quartiles of SES score, there were similar values for age (56 [12] vs 55 [13] years), male sex (2333 [65%] vs 2346 [66%]), black race (279 [8%] vs 297 [8%]), and current smoking status (723 [20%] vs 707 [20%]). Compared with the 7158 matched patients, the 7818 unmatched patients in the 2 extreme quartiles were similar in age (53 [12] vs 55 [12] years), male sex (4993 [64%] vs 4679 [65%]), and current smoking status (1564 [20%] vs 1430 [20%]), but were much more likely to be of black race (3328 [43%] vs 576 [8%]). The  $c$ -statistic for the logistic model creating the matched cohort was 0.84, indicating good discrimination.

After accounting for selection bias in this way, we observed that being in the lowest quartile of the SES score re-

**Figure 3.** Kaplan-Meier Curves Showing the Association of Quartiles of Socioeconomic Status Score With All-Cause Mortality

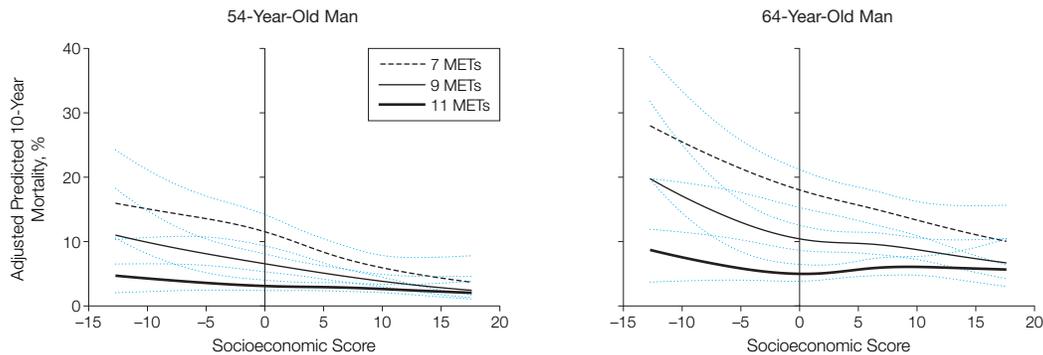


Error bars indicate 95% confidence intervals.

mained independently associated with a greater likelihood of impaired functional capacity (32% vs 17%, propensity-adjusted odds ratio [OR], 2.34; 95% CI; 2.09-2.63;  $P<.001$ ) and with abnormal heart rate recovery (23% vs 18%, propensity-adjusted OR, 1.37; 95% CI, 1.22-1.53;  $P<.001$ ). Lower SES was predictive of increased mortality (11% vs 6%, adjusted HR, 1.84; 95% CI, 1.56-2.17;  $P<.001$ ).

We performed a similar matched propensity analysis for all-cause mortal-

ity, in which functional capacity and heart rate recovery were also included. This increased the  $c$ -statistic to 0.85, again indicating very good discrimination. We were able to successfully match 3382 patients in the lowest quartile to 3382 patients in the highest quartile. In this propensity-matched cohort there were 553 deaths. Although we observed that being in the lowest SES score quartile was associated with an increased risk of death, the association was 44% weaker than the

**Figure 4.** Adjusted Predicted 10-Year Mortality for 2 Patients According to Socioeconomic Status Score, Stratified by Metabolic Equivalents (METs)

Values are based on Cox proportional hazard models. Continuous variables are set to median values while categorical variables are set to modes. METs refer to estimated exercise capacity where 1 metabolic equivalent=3.5 mL/kg/min of oxygen consumption. Shown here are 75th (11.0), 50th (9.0), and the 25th (7.0) percentiles of metabolic equivalents for individuals between the ages of 59 to 69 years. Dotted blue lines indicate 95% confidence intervals.

propensity-matched analysis that did not account for exercise variables (10% vs 7%, propensity-adjusted HR, 1.47; 95% CI, 1.24-1.74;  $P < .001$ ).

### Supplemental Analyses

Analyses based on 1990 census data and a simpler measure of poverty (ie, proportion of residents with incomes below the poverty level) yielded similar results to those using data from the 2000 census. Further subgroup analyses adjusting for left ventricular ejection fraction and presence of ischemia or scar had no significant impact on the associations between SES score, functional capacity, heart rate recovery, and mortality. When we accounted for clustering by physician ordering location instead of census block, we obtained materially similar results (Table 3).

Among the 24 731 patients with known employment status, SES score was independently associated with impaired functional capacity and heart rate recovery (Table 3) even after accounting for employment. Of note, being unemployed was independently predictive of impaired functional capacity (adjusted OR, 1.62; 95% CI, 1.44-1.80;  $P < .001$ ), whereas being retired was not independently predictive. In this same model, other measures of individual SES that were predictive included Medicaid insurance (adjusted

OR, 1.20; 95% CI, 1.07-1.35;  $P < .001$ ) and distance from a patient's home to the main campus medical center ( $P < .001$ ).

### COMMENT

In a large clinical cohort of patients referred for exercise stress testing for evaluation of known or suspected coronary artery disease, we identified independent associations between SES and functional capacity, and heart rate recovery. These physiologic characteristics accounted for a substantial portion of the association between SES and all-cause mortality. The current findings support strategies that extend targets for interventions beyond purely biological characteristics of individuals to those addressing social or economic factors that influence health.

The 2 physiological indicators were selected for several reasons based on basic, clinical, and epidemiological research. Functional capacity has been mechanistically linked to obesity, hypertension, inflammation, and insulin resistance,<sup>16,20,39,40</sup> and has been used to assess cardiovascular risk in many settings.<sup>24,41-44</sup> Heart rate recovery reflects autonomic function and has been associated with glucose intolerance, insulin resistance, the metabolic syndrome, smoking, education level, and all-cause mortality.<sup>22,34,35,45-50</sup> Autonomic dysfunction has been linked to

inflammation, psychosocial stress, and depression, conditions that are prevalent in economically disadvantaged individuals.<sup>21,22,50-53</sup> Both physiological characteristics are potentially modifiable. Myers et al<sup>42</sup> found that each 1 metabolic equivalent increase in functional capacity conferred a 12% survival improvement. Observational studies have also shown that heart rate recovery improves following cardiac rehabilitation.<sup>48,54</sup>

Our findings may have important public health implications. First, functional capacity and heart rate recovery may be particularly useful for identifying economically disadvantaged patients who are potentially at greatest risk. Such an inclusive approach to risk assessment, combining individual clinical data with SES factors, may have the added benefit of reducing well-recognized disparities in health outcomes associated with economic disadvantage, a goal outlined in the Healthy People 2010 report and in a report on health care delivery in the United States issued by the Institute of Medicine.<sup>55,56</sup> Second, use of these physiological characteristics may also prove valuable as a means of monitoring the effectiveness of community-based interventions to reduce disparities in mortality. Third, given the link between functional capacity, heart rate recovery, and mortality, our data lend

support to a public policy approach that invests in, for example, recreational facilities.

We identified several interactions between sociodemographic variables and functional capacity that should serve as the basis for future study. We observed a stronger association between SES score and functional capacity among younger individuals (Figure 1). Similarly, there was an age interaction between SES and mortality, whereby the association between SES score and mortality was significantly stronger for younger individuals (Figure 4A and Figure 4B). These findings are consistent with findings from a large European cohort in which the associations of SES and ischemic heart disease mortality were less marked among older patients.<sup>57</sup> Although mechanisms for these interactions are uncertain, potential hypotheses include better coping skills at older ages, perhaps due to having lived longer under unfavorable socioeconomic circumstances, and increased access to health care through public insurance programs available to older individuals. Finally, we observed a strong interaction between functional capacity, SES, and mortality (Figure 4A and Figure 4B).

Our study has several limitations. First, this sample included individuals referred to a tertiary care facility for exercise testing and may not represent residents of the 7-county service area who did not have the means to seek evaluation at the facility. We performed a propensity analysis and found no material change in the results. Second, these study participants may not be representative of the US population, mandating further investigation using different patient populations. Third, we cannot conclude that our observed associations are causal. Fourth, we had limited direct measures of individual SES, namely insurance status, distance from home to hospital, and employment for a subset; we did not have information about measures that sometimes serve as proxies for an individual's SES including educational attainment, income, and home ownership.<sup>8,28,29</sup> Fifth, we were unable

to account for patient migration from or to neighborhoods, an occurrence that may have introduced variable exposure to neighborhood effects and the outcomes we studied. We suspect, however, that the mobility of participants in our study would have attenuated the true association between the factors we studied. Finally, it is conceivable that some of the variables we treated as confounders, such as blood pressure, may actually be part of a causal mechanistic pathway linking SES with physiological abnormalities. If true, this would make our estimates conservative.

The association between SES, functional capacity, and heart rate recovery represents a potential explanatory mechanism for greater all-cause mortality among individuals who are impoverished. In clinical practice, however, SES often receives little attention.<sup>2,6,28,58</sup> If confirmed in other settings, our report of independent associations between SES, prognostically important physiological measures, and mortality argue for a greater degree of attention to socioeconomic factors in routine clinical risk stratification. From a health policy perspective, our results also support the value of currently ongoing community-based interventions to enhance economic conditions as a means of improving health.<sup>59,60</sup> Although these studies have not yet demonstrated effects on mortality, an approach that explicitly addresses the contribution of adverse socioeconomic exposures to health represents a promising strategy for reducing poverty-related health disparities.

**Author Contributions:** Dr Lauer had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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