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Exercise Capacity, Heart Failure Risk, and Mortality in Older Adults: The Health ABC Study

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Abstract

Introduction—Data on the association between exercise capacity and risk for heart failure (HF) in older adults are limited.

Methods—This study examined the association of exercise capacity, and its change over time, with 10-year mortality and incident HF in 2,935 participants of the Health, Aging, and Body Composition Study without HF at baseline (age, 73.6 [SD=2.9] years; 52.1% women; 41.4% black; 58.6% white). This cohort was initiated in 1997–1998 and exercise capacity was evaluated with a long distance corridor walk test (LDCW) at baseline and Year 4. Outcomes were collected in 2007–2008 and initial analysis performed in 2014.

Results—Ten-year incident HF for completers (n=2,245), non-completers (n=331), and those excluded from LDCW for safety reasons (n=359) was 11.4%, 19.2%, and 23.0%, respectively. The corresponding 10-year mortality was 27.9%, 41.1%, and 42.4%. In models accounting for competing mortality, the adjusted subhazard ratio for HF was 1.37 (95% CI=1.00, 1.88, p=0.049) in non-completers and 1.41 (95% CI=1.06, 1.89, p=0.020) in those excluded versus completers.
Non-completers (adjusted hazard ratio, 1.49; 95% CI=1.21, 1.84; p<0.001) and those excluded (hazard ratio, 1.27; 95% CI=1.04, 1.55, p=0.016) had elevated mortality. In adjusted models, LDCW performance variables were associated mainly with mortality. Only 20-meter walking speed and resting heart rate retained prognostic value for HF. Longitudinal changes in LDCW did not predict subsequent incident HF or mortality.

Conclusions—Completing an LDCW is strongly associated with lower 10-year mortality and HF risk in older adults. Therefore, walking capacity may serve as an early risk marker.

INTRODUCTION

Exercise capacity is an important indicator of health status and longevity and reflects functional reserves of body systems. Impaired exercise capacity indicates impaired function of body systems and has been associated with increased mortality irrespective of gender, race, or age.\(^2\)\textsuperscript{–}\(^8\) Low exercise capacity has been associated with risk for hypertension,\(^9\) diabetes mellitus,\(^10\) and cardiovascular events.\(^11\) Responses of the cardiovascular system during exercise strongly predict cardiovascular disease (CVD) and mortality.\(^12\)\textsuperscript{–}\(^15\) However, data on the association of exercise capacity with risk for heart failure (HF) are limited,\(^16\)\textsuperscript{–}\(^17\) especially in older adults, who are the population segment with the highest incidence and prevalence of HF.\(^18\)

Tests of varying complexity have been used to evaluate exercise capacity, ranging from distance completed in a predefined time (e.g., the 6-minute walk test) to simultaneous acquisition of several cardiovascular, ventilatory, and gas exchange variables (cardiopulmonary exercise testing). The latter provide pathophysiologic insights that are important for diagnosis,\(^19\) risk assessment,\(^19\) and decision making\(^19\); however, these tests cannot be widely performed owing to the requirement of special equipment and expertise. Therefore, walking tests have been introduced, allowing for wider implementation of exercise capacity testing; and evaluation of patients who are unable to complete complex protocols because of underlying comorbidities or advanced age. Although the 6-minute walk test is easy to perform, correlates with oxygen consumption,\(^20\)\textsuperscript{–}\(^21\) and has prognostic value in chronic conditions,\(^22\)\textsuperscript{–}\(^23\) it has some disadvantages, including a low test ceiling,\(^24\) subject motivation,\(^25\)\textsuperscript{–}\(^26\) and learning effects.\(^27\) To overcome these drawbacks, the long distance corridor walk test (LDCW) was introduced in the Health, Aging, and Body Composition (Health ABC) study.\(^28\)\textsuperscript{–}\(^31\) The LDCW helps older individuals approach their maximum capacity,\(^28\) correlates strongly with oxygen consumption,\(^32\) and carries important prognostic information for disability, CVD, and all-cause mortality.\(^7\) However, the value of LDCW and, importantly, the value of changes in exercise performance over time for HF risk prediction, have not been evaluated.

In this study, the association of LDCW parameters, and their change over time, with long-term risk for all-cause mortality and incident HF, using 10-year follow-up data from the Health ABC study was examined. In secondary analyses, the association of LDCW parameters with outcomes of interest in sex and race subgroups and in participants with and without CVD at baseline was examined.
METHODS

Study Population

The Health ABC study is a community-based study of 3,075 well-functioning individuals aged 70–79 years at inception (April 1997–June 1998).\textsuperscript{7,33} Exclusion criteria included difficulty walking a quarter of a mile, climbing stairs or performing basic activities of daily living, obvious cognitive impairment, inability to communicate, anticipated move within 3 years, or participation in a trial involving lifestyle intervention.\textsuperscript{33} The IRBs at both sites and the coordinating center approved the study. At baseline and at Year 4, participants were asked to undergo a LDCW test to evaluate their exercise capacity. This analysis included data on 2,935 participants; 140 participants with either prevalent HF or inconclusive or missing data on HF at baseline were excluded. For outcomes, adjudicated 10-year follow-up data, collected in 2007–2008, were used. Initial analysis of these data was performed in 2014.

Measures

The LDCW was used as an objective measure of participants’ exercise capacity and as a verification of their self-reported ability to walk a quarter of a mile. Participants were divided into:

1. completers, those who completed the LDCW test;
2. non-completers, those who started but did not complete both phases of the LDCW test; and
3. those excluded from LDCW for safety reasons because of electrocardiogram abnormalities, elevated blood pressure (\textsuperscript{\textgreater}200/110 mmHg), resting heart rate (\textsuperscript{\textgreater}135 beats/minute or \textless;40 beats/minute), recent exacerbation of chest pain, shortness of breath, or a recent cardiac event or procedure.

The LCDW test has two stages.\textsuperscript{34} Stage 1 is a 2-minute warm-up. The walking speed to cover the first 20 meters of the warm-up was recorded and the steps needed to complete 20 meters were also measured. Stage 2 is a 400-meter walk in a hallway, where participants are instructed to walk as quickly as they can at a steady pace. Standardized encouragement was given. Heart rate was monitored continuously. Participants could stop the test because of fatigue or symptoms. The staff stopped the test if persistent tachycardia (\textsuperscript{\textgreater}135 beats/minute) occurred. The distance covered in the first 2 minutes and the time needed for completion of the 400-meter walk were recorded. Blood pressure and heart rate response, including heart rate recovery (change from the end of test until 2 minutes after) were also recorded.

Race was self-defined by participants. Smoking was defined as current, past (\textgreater;100 lifetime cigarettes), or never. Leg length was calculated as the average standing height measurement minus the hip-to-head measurement. Physical activity was determined using a standardized questionnaire designed specifically for the Health ABC study.\textsuperscript{35,36}

Baseline CVD status (including HF) was based on ICD 9-CM codes as reported by Medicare Services for years 1995–1998, self-reported history, and medications. Following
the definitions used in previous Health ABC work,\textsuperscript{7,37} prevalent CVD was defined as prevalent:

1. coronary heart disease;
2. cerebrovascular disease; or
3. peripheral vascular disease.

Incident CVD was defined as:

1. incident coronary heart disease;
2. incident cerebrovascular disease;
3. incident peripheral arterial disease; or
4. death due to cardiovascular causes.

Definitions of diabetes, hypertension, depression, and pulmonary disease used in previous studies were followed.\textsuperscript{33,38} Left ventricular hypertrophy was determined from electrocardiography.\textsuperscript{38}

Participants were surveyed every 6 months for interim events. Local adjudicators reviewed medical records for overnight hospitalizations. Using algorithms mirroring those of the Cardiovascular Health Study, a panel of clinicians verified diagnoses and causes of death based on interview, review of hospital records, and death certificates. All first admissions with an overnight stay confirmed as related to HF, using the criteria of the Cardiovascular Health Study, were considered as incident HF events.\textsuperscript{39} The criteria required HF diagnosis by a physician and treatment for HF.\textsuperscript{40} Briefly, HF was confirmed if there was documentation of symptoms and signs, supporting imaging findings, or medical therapy for HF, including at least a diuretic and a vasodilator or digitalis. Incident CVD events were identified and adjudicated using the standard Health ABC surveillance and adjudication process described above. The Health ABC Diagnosis and Disease Ascertainment Committee reviewed all deaths.

**Statistical Analysis**

Differences in baseline characteristics across LDCW completion categories were examined with the Kruskal–Wallis and chi-square tests for continuous and categorical variables, respectively. The association of LDCW performance and cardiovascular response parameters with mortality was examined with Cox proportional hazards models. For incident HF, Fine and Gray models were used to account for competing mortality.\textsuperscript{41} The analyses for changes from Year 1 to Year 4 and subsequent mortality and incident HF were repeated. A simulation approach (PROC PHREG/ASSESS) was used to identify potential nonlinear associations of LDCW parameters with the events of interest. The proportional hazards assumption was evaluated using the Schoenfeld residuals for Cox models and interaction terms with time for Fine and Gray models.

Multivariable analyses included:
1. risk factors previously associated with mortality and incident HF in Health ABC;
2. factors that could affect exercise capacity; and
3. additional baseline characteristics associated with exercise capacity.

All tests of hypotheses were two-sided at the $\alpha=0.05$ level. Analyses were performed with Stata, version 13.1 and SAS, version 9.4.

RESULTS

The mean age of participants (N=2,935) was 73.6 (SD=2.9) years, 52.1% were women, and 41.4% were black. Table 1 summarizes the baseline characteristics according to LDCW test completion category. Men, whites, and participants with greater reported physical activity were more likely to complete the test. Those with hypertension, diabetes, and CVD were more likely to stop. Lower resting heart rate and systolic blood pressure, and absence of electrocardiographic abnormalities were associated with test completion. Performance data and cardiovascular responses of test completers are summarized in Table 2.

After 10 years of follow-up, 620/2,245 test completers died as compared with 135/331 test non-completers and 151/359 participants who were excluded. The corresponding Kaplan–Meier estimates for 10-year mortality were 27.9% (95% CI=26.1%, 29.8%), 41.1% (95% CI=36.0%, 46.7%), and 42.4% (95% CI=37.4%, 47.8%) (log-rank chi-square=52.2, $p<0.001$, Figure 1A). Among completers, 253 (11.3%) developed HF as compared with 63 (19.0%) among non-completers and 82 (22.8%) among those who were excluded. The 10-year cumulative HF incidence was 11.4% (95% CI=10.2%, 12.7%), 19.2% (95% CI=15.8%, 23.3%), and 23.0% (95% CI=18.9%, 27.9%), respectively (Figure 1B).

In unadjusted models, the mortality hazard ratio (HR) was 1.69 (95% CI=1.41, 2.02, $p<0.001$) for those excluded and 1.64 (95% CI=1.36, 1.98, $p<0.001$) for non-completers, with completers as reference. In models adjusting for the covariates described in Table 1, the increased mortality risk persisted; the adjusted HR was 1.27 (95% CI=1.04, 1.55, $p=0.016$) for those excluded and 1.49 (95% CI=1.21, 1.84, $p<0.001$) for non-completers.

In models accounting for competing mortality, the subhazard ratio (sHR) for HF was 2.17 (95% CI=1.69, 2.79, $p<0.001$) for those excluded and 1.77 (95% CI=1.34, 2.33, $p<0.001$) for non-completers, with completers as reference. In competing-risks models adjusting for the covariates described in Table 1, sHR for HF was 1.41 (95% CI=1.06, 1.89, $p=0.020$) for those excluded and 1.37 (95% CI=1.00, 1.88, $p=0.049$) for non-completers.

Among completers ($n=2,245$), all exercise performance variables were strongly associated with 10-year mortality in unadjusted and adjusted models, with the walking speed to cover 400 meters being the strongest predictor (Table 3). Specifically, mortality risk was lower by approximately 78% for every meter/second-faster walking speed. Among cardiovascular responses, univariate predictors of mortality were (Table 3):

1. heart rate change from rest to 2 minutes and 400 meters;
2. heart rate recovery; and
3. change in diastolic blood pressure.

However, these associations were attenuated in adjusted models; only the change in diastolic blood pressure retained a trend toward statistical significance with risk increasing in parallel with diastolic blood pressure increases.

All exercise performance variables, baseline systolic blood pressure and heart rate, and change in heart rate from rest to 2 minutes were associated with increased risk of HF in univariate models (Table 3). Higher walking speed to cover the first 20 meters of the warm-up phase, the 400 meters of the second phase, and larger distance covered during the warm-up phase were associated with lower HF risk. Higher baseline systolic blood pressure and heart rate were associated with higher HF risk. However, in adjusted models, only the walking speed to cover the first 20 meters of the warm-up phase and the baseline heart rate retained statistical significance (Table 3). Specifically, for every meter/second-faster walking speed, the HF risk was lower by approximately 55%.

**Subgroup Analyses**

Analyses for significant interactions between LDCW responses and sex, race, and baseline CVD for mortality and incident HF risk were performed. Systolic blood pressure response to LDCW was differentially associated with 10-year mortality in men versus women; SBP at the end of 400-meter walk had an unadjusted HR of 0.996 per mmHg (95% CI=0.992, 1.000, p=0.073) in men versus 1.007 (95% CI=1.002, 1.012, p=0.007) in women (p=0.001 for interaction). This interaction persisted in adjusted models (p=0.018), although the individual HRs were not statistically significant: 1.000 per mmHg (95% CI=0.994, 1.005, p=0.86) in men versus 1.003 (95% CI=0.996, 1.009, p=0.45) in women. No other significant interactions were detected.

Both the absolute values of Year 4 LDCW parameters and the corresponding changes from baseline as predictors for the remaining 6-year horizon were evaluated. Among the 2,245 participants who completed the test at baseline, 1,418 (63.2%) participants without interim HF completed the Year 4 LCDW test. Although overall speed to complete 400 meters decreased by 0.03 (SD=0.12) meters/second (p<0.001) to 1.25 (SD=0.21) meters/second, the distance covered during the first 2 minutes increased by 1.8 (SD=21.6) meters (p=0.001) to 162 (SD=27) meters.

The association of LDCW performance with mortality among Year 4 completers is presented in Appendix Table 1. In unadjusted models, both absolute values of distance covered by 2 minutes and speed to walk 400 meters and their changes from Year 1 to Year 4 were associated with mortality. However, in adjusted analysis, only absolute values at Year 4 retained statistical significance (Appendix Table 1). Neither absolute Year 4 LDCW performance variables nor their changes from Year 1 demonstrated significant associations with incident HF (data not shown).
DISCUSSION

In this study, an association between exercise capacity, assessed by the LDCW test, and incident HF among older adults participating in the Health ABC study was observed. Also, the ability to complete the LDCW test was a strong predictor of both 10-year incident HF and 10-year mortality. A strong association was also observed between baseline exercise capacity and long-term mortality among these healthy older individuals. All measures of LDCW performance were predictors of mortality, the strongest being the speed to cover 400 meters. Among the measures of LDCW performance, walking speed over the first 20 meters of the warm-up phase was the stronger predictor of incident HF. Another important finding of this study was that changes in exercise capacity from Year 1 to 4 were not associated with subsequent mortality, although the absolute performance at Year 4 was strongly associated with death over the next 6 years. Year 4 LDCW performance did not predict subsequent incident HF, perhaps reflecting selection bias since only relatively fit participants were still alive and able to take the Year 4 test. This is the first study reporting on the association of exercise capacity and its longitudinal changes with mortality and incident HF in a well-functioning older population.

Most data on the association between exercise capacity and mortality come from studies using laboratory tests. Limited data have linked performance in walking tests with mortality in healthy individuals. The findings of this study on mortality are in accordance with the findings of a study by Stanaway et al., where walking speed of ≤0.82 meters/second was associated with high mortality in older healthy individuals. The current study expands the previous findings on mortality with a longer-term follow-up (10 years), data on HF risk, and competing risks estimates for HF to account for the high rates of 10-year mortality in this older population. Although walking tests are often used in populations with chronic health conditions, these inexpensive tests can also be useful in healthy individuals and especially older adults, who may have difficulty undergoing a laboratory exercise test. This is further supported by the association of LDCW performance with clinical or subclinical disease in older adults.

The observed weak association between exercise performance and incident HF are not aligned with recent data on the prognostic value of exercise performance for incident HF in middle-aged adults. In these studies, the evaluation of exercise capacity was done by maximal exercise tests. There are important differences in the granularity of information gained from field and laboratory tests. For example, heart rate or blood pressure increases are smaller during field tests. However, field tests represent activities of daily living better than laboratory tests, thus offering significant information on health status. The discrepancy of the prognostic value of laboratory versus field tests cannot be attributed solely to the different exercise testing methods. A possible explanation could be that Health ABC Study participants were well-functioning individuals by design. Also, considering that mortality is higher in this age group than in middle-aged adults, the association of exercise capacity with HF may be attenuated because of competing mortality. Finally, the authors adjusted for a large array of risk factors associated with incident HF. These risk factors have also been associated with exercise capacity, and therefore confounding may be an additional explanation for the attenuated association of exercise capacity with HF risk in this study.
Several possible mechanisms could link exercise capacity to risk for HF. Physical inactivity leads to elevated levels of blood pressure and serum lipids, insulin resistance, and obesity, all of which predispose to the development of HF.\textsuperscript{10,45} On the other hand, regular physical activity may increase the capacity of endothelial cells to evoke vasodilatation in the early stages of atherosclerosis, thus retarding its progression and preventing CVD development.\textsuperscript{46,47} Physical activity also protects against the development of CVD by favorably affecting risk factors\textsuperscript{48–54} and may help improve cardiac output, left ventricular function and oxygen utilization, and the formation of collateral vessels.\textsuperscript{46,55,56} Physical activity seems to regulate cardiac autonomic function and vagal control of heart rate, therefore reducing risk of ventricular arrhythmias and subsequent risk of HF.\textsuperscript{57} This is supported in this study also, as resting heart rate remained an independent risk factor for HF development.

In this population, there was a small decline in exercise performance over time, with a decrease of average walking speed beyond 400 meters. Although exercise capacity at Year 4 was strongly associated with mortality, it was not associated with HF, a finding that supports the assumption that mortality may precede HF development in older adults and especially in those of higher risk, inducing selection bias over time.

**Limitations**

This study has several limitations. Although participants were well characterized, thus providing sufficient information to control for confounders and arrive at conclusions as valid as possible, unobserved confounding cannot be excluded. Selection bias toward healthier older adults is inherent in this study. Thus, these findings apply only to well-functioning older adults. Careful interpretation is required for other older adult groups. Considering the 10-year horizon, the possibility of regression dilution cannot be excluded. Although there is some potential for bias because of loss to follow-up, the retention rate in the study was very high, limiting this bias. Older age is associated with higher mortality rates, which can affect estimates for competing outcomes. However, in this analysis, the authors did account for death as a competing event factor in incident HF analyses to avoid inflation of HF risk estimates.

**CONCLUSIONS**

This study highlights the strong prognostic value of exercise capacity as evaluated by a field test (LDCW) with mortality and risk for HF in well-functioning older adults, despite the association of exercise capacity with HF risk being weaker. In addition, longitudinal changes in exercise capacity were not associated with mortality or HF risk. However, older adults have a higher competing risk for mortality before developing HF. Therefore, interventional studies are needed to evaluate whether improved exercise capacity may result in improved survival, less HF, and better quality of life.

**Supplementary Material**

Refer to Web version on PubMed Central for supplementary material.
Acknowledgments

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Dr. Georgiopoulou had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design, data analysis: Kalogeropoulos. Data interpretation, drafting: All authors. Revisions, important intellectual content: All authors. Design of Health ABC Study, obtained funding: Newman, Harris, Kritchevsky.

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References


Figure 1.
Kaplan-Meier curve of mortality (A) and incident heart failure (B) according to long distance corridor walk completion status.
## Table 1
Baseline Participant Characteristics According to Completion Categories at Baseline

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Excluded</th>
<th>Stopped</th>
<th>Completed</th>
<th>p-value$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=359</td>
<td>n=331</td>
<td>n=2245</td>
<td></td>
</tr>
<tr>
<td>Age, years</td>
<td>74.1 (2.9)</td>
<td>73.9 (2.9)</td>
<td>73.5 (2.8)</td>
<td>0.001</td>
</tr>
<tr>
<td>Male sex, N (%)</td>
<td>161 (44.8%)</td>
<td>110 (33.2%)</td>
<td>1136 (50.6%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Blacks, N (%)</td>
<td>185 (51.5%)</td>
<td>184 (55.6%)</td>
<td>846 (37.7%)</td>
<td></td>
</tr>
<tr>
<td>Whites, N (%)</td>
<td>174 (48.5%)</td>
<td>147 (44.4%)</td>
<td>1399 (62.3%)</td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>27.9 (5.4)</td>
<td>28.8 (5.8)</td>
<td>27 (4.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current smokers, N (%)</td>
<td>47 (13.1%)</td>
<td>42 (12.7%)</td>
<td>219 (9.8%)</td>
<td></td>
</tr>
<tr>
<td>Past smokers, N (%)</td>
<td>162 (45.1%)</td>
<td>146 (44.1%)</td>
<td>1011 (45.0%)</td>
<td></td>
</tr>
<tr>
<td>Standing height, mm</td>
<td>1655.0 (96.1)</td>
<td>1631.0 (92.6)</td>
<td>1667.0 (92.9)*</td>
<td></td>
</tr>
<tr>
<td>Leg height, mm</td>
<td>817.0 (67.3)</td>
<td>798.0 (63.4)</td>
<td>818.0 (62.8)**</td>
<td></td>
</tr>
<tr>
<td>Steps to complete first 20 m</td>
<td>-</td>
<td>32.5 (5.76)</td>
<td>29.9 (4.16)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Physical activity, kcal/kg/week</td>
<td>73.9 (72)</td>
<td>76.3 (71)</td>
<td>86.2 (69)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hypertension, N (%)</td>
<td>194 (54.0%)</td>
<td>169 (51.1%)</td>
<td>901 (40.1%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes mellitus, N (%)</td>
<td>69 (19.2%)</td>
<td>67 (20.2%)</td>
<td>295 (13.1%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Left ventricular hypertrophy, N (%)</td>
<td>65 (18.1%)</td>
<td>42 (12.7%)</td>
<td>241 (10.7%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Coronary heart disease, N (%)</td>
<td>96 (26.7%)</td>
<td>65 (19.6%)</td>
<td>315 (14.0%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cerebrovascular disease, N (%)</td>
<td>31 (8.6%)</td>
<td>34 (10.3%)</td>
<td>133 (5.9%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Peripheral vascular disease, N (%)</td>
<td>18 (5.2%)</td>
<td>36 (11.4%)</td>
<td>82 (3.7%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Any cardiovascular disease, N (%)</td>
<td>122 (34.0%)</td>
<td>89 (26.9%)</td>
<td>445 (19.8%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pulmonary disease, N (%)</td>
<td>34 (9.5%)</td>
<td>14 (4.2%)</td>
<td>69 (3.1%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Depression, N (%)</td>
<td>52 (14.5%)</td>
<td>29 (8.8%)</td>
<td>224 (10.0%)</td>
<td>0.019</td>
</tr>
<tr>
<td>Systolic blood pressure, mmHg</td>
<td>143 (29)</td>
<td>138 (20)</td>
<td>135 (19)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diastolic blood pressure, mmHg</td>
<td>73.5 (15)</td>
<td>71.1 (11)</td>
<td>71.2 (11)</td>
<td>0.15</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>68.3 (14)</td>
<td>68.5 (12)</td>
<td>64.4 (10)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ECG – major abnormalities, b N (%)</td>
<td>113 (31.6%)</td>
<td>87 (26.3%)</td>
<td>422 (18.8%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ECG – minor abnormalities, c N (%)</td>
<td>75 (21.1%)</td>
<td>60 (18.1%)</td>
<td>358 (16.0%)</td>
<td>0.064</td>
</tr>
<tr>
<td>Fasting Glucose, mg/dl</td>
<td>109 (45)</td>
<td>110 (40)</td>
<td>102 (31)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Albumin, g/dl</td>
<td>3.97 (0.32)</td>
<td>3.97 (0.32)</td>
<td>3.98 (0.31)</td>
<td>0.70</td>
</tr>
<tr>
<td>Creatinine, mg/dl</td>
<td>1.09 (0.4)</td>
<td>1.07 (0.54)</td>
<td>1.04 (0.39)</td>
<td>0.047</td>
</tr>
<tr>
<td>Total cholesterol, mg/dl</td>
<td>203 (41)</td>
<td>207 (37)</td>
<td>203 (38)</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Notes: Continuous variables are presented as mean (SD) or median (25th percentile, 75th percentile); categorical variables are presented as number (%). Boldface indicates statistical significance (*p-value 0.024 for comparison between those who excluded vs. those who completed the test; p-value <0.001 for comparison between those who excluded vs. those who stopped and between those who stopped vs. those who completed the test; **p-value <0.001 for comparison between those excluded or completed the test vs. those who stopped).

$^a$Nonparametric test for trend.

$^b$Major Q or QS abnormality, major ST or T wave abnormality, left ventricular hypertrophy, atrioventricular conduction defect, ventricular conduction defects, rhythm irregularity.

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Minor Q or QS abnormality or ST or T wave abnormalities.

ECG, electrocardiogram
### Table 2

Summary of Responses to LDCW Test Among Completers (n=2,245)

<table>
<thead>
<tr>
<th>Response variable</th>
<th>Mean (SD)</th>
<th>Median (Q1-Q2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking speed over 20 m, m/s</td>
<td>1.35 (0.24)</td>
<td>1.34 (1.19–1.5)</td>
</tr>
<tr>
<td>Distance covered by 2 min, m</td>
<td>155 (26)</td>
<td>155 (138–173)</td>
</tr>
<tr>
<td>Time to walk 400 m - complete only, s</td>
<td>331 (61)</td>
<td>323 (289–361)</td>
</tr>
<tr>
<td>Speed to walk 400 m, m/s</td>
<td>1.24 (21)</td>
<td>1.24 (1.11–1.38)</td>
</tr>
<tr>
<td>Standing SBP, mmHg</td>
<td>138 (21)</td>
<td>136 (124–150)</td>
</tr>
<tr>
<td>SBP at the end of 400 m, mmHg</td>
<td>149 (24)</td>
<td>148 (132–164)</td>
</tr>
<tr>
<td>Standing DBP, mmHg</td>
<td>77 (13)</td>
<td>78 (70–86)</td>
</tr>
<tr>
<td>DBP at the end of 400 m, mmHg</td>
<td>76 (14)</td>
<td>78 (70–86)</td>
</tr>
<tr>
<td>Resting heart rate, beats/min</td>
<td>78 (19)</td>
<td>78 (69–87)</td>
</tr>
<tr>
<td>Heart rate at the end of 2 min, beats/min</td>
<td>100 (15)</td>
<td>101 (90–111)</td>
</tr>
<tr>
<td>Heart rate at the end of the 400 m, beats/min</td>
<td>104 (15)</td>
<td>104 (93–115)</td>
</tr>
<tr>
<td>Heart rate at min 2 of recovery, beats/min</td>
<td>87 (15)</td>
<td>88 (77–98)</td>
</tr>
</tbody>
</table>

LDCW, long distance corridor walk test; DBP, diastolic blood pressure; SBP, systolic blood pressure
Table 3
Exercise and Cardiovascular Responses and Association With 10-year Mortality and Heart Failure Incidence Among Completers (n=2,245)

<table>
<thead>
<tr>
<th>Response variable</th>
<th>Mortality</th>
<th>Incident heart failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unadjusted HR (95% CI)</td>
<td>Adjusted* HR (95% CI)</td>
</tr>
<tr>
<td>Walking speed over first 20 m, per m/s</td>
<td>0.348 (0.249–0.487)***</td>
<td>0.512 (0.285–0.922)*</td>
</tr>
<tr>
<td>Distance covered by 2 min, per m</td>
<td>0.990 (0.987–0.993)***</td>
<td>0.993 (0.988–0.998)**</td>
</tr>
<tr>
<td>Speed to walk 400 m, per m</td>
<td>0.219 (0.149–0.322)***</td>
<td>0.280 (0.149–0.526)***</td>
</tr>
<tr>
<td>Standing SBP, per mmHg</td>
<td>1.001 (0.997–1.006)</td>
<td>1.006 (0.996–1.015)</td>
</tr>
<tr>
<td>Δ SBP at 400 m, per mmHg</td>
<td>1.000 (0.995–1.004)</td>
<td>0.999 (0.994–1.004)</td>
</tr>
<tr>
<td>Standing DBP, per mmHg</td>
<td>0.998 (0.991–1.005)</td>
<td>0.996 (0.988–1.005)</td>
</tr>
<tr>
<td>Δ DBP at 400 m, per mmHg</td>
<td>1.008 (1.001–1.015)*</td>
<td>1.007 (0.999–1.015)</td>
</tr>
<tr>
<td>Resting heart rate, per beat/min</td>
<td>1.003 (1.000–1.006)*</td>
<td>1.001 (0.997–1.005)</td>
</tr>
<tr>
<td>Δ Heart rate by 2 min, per beat/min</td>
<td>0.986 (0.980–0.993)***</td>
<td>0.997 (0.990–1.005)</td>
</tr>
<tr>
<td>Δ Heart rate at 400 m, per beat/min</td>
<td>0.988 (0.982–0.995)***</td>
<td>0.999 (0.992–1.006)</td>
</tr>
<tr>
<td>Heart rate recovery, c per beat/min</td>
<td>1.014 (1.007–1.022)***</td>
<td>1.004 (0.996–1.013)</td>
</tr>
</tbody>
</table>

Note: Boldface indicates statistical significance (*p<0.05; **p<0.01; ***p<0.001).

* Adjusted for variables in Table 1 (age, gender, race, BMI, standing height, leg height, steps to complete first 20 meters, smoking, self-reported physical activity, prevalent cardiovascular disease [coronary artery disease, cerebrovascular disease, and peripheral vascular disease], pulmonary disease, diabetes mellitus, hypertension, depression, systolic blood pressure, heart rate, electrocardiographic abnormalities, blood glucose, and serum levels of albumin, creatinine, and cholesterol).

b p=0.07

Defined as heart rate 2 min after the test minus the heart rate at 400 m.

DBP, diastolic blood pressure; Δ, difference; SBP, systolic blood pressure.