



The impact of moderate intensity physical activity on cardiac structure and performance in older sedentary adults[☆]



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ABSTRACT

Background: Sedentary aging leads to adverse changes in vascular function and cardiac performance. We published improvements in vascular function with moderate intensity physical activity (PA) in continuous bouts. Whether moderate intensity PA also impacts cardiac structure and cardiovascular performance of the aging left ventricle (LV) is unknown.

Methods: We recruited and analyzed results from 102 sedentary older adults ages ≥ 50 from a randomized controlled trial with 3 study groups: control (group 1), a pedometer-only intervention (group 2), or a pedometer with an interactive website employing strategies to increase habitual physical activity (PA, group 3) for 12 weeks. Transthoracic echocardiograms were performed prior to and following the 12 week intervention period to assess cardiac morphology, left ventricular (LV) systolic performance, LV diastolic function, and arterial and LV ventricular elastance. Step count and PA intensity/distribution were measured by a pedometer and an accelerometer.

Results: We found no significant changes in cardiac morphology. Further, we found no improvement in the aforementioned cardiac functional parameters. Comparing those who achieved the following benchmarks to those who did not showed no significant changes in cardiac structure or performance: 1) 10,000 steps/day, 2) ≥ 30 min/day of moderate intensity physical activity, or 3) moderate intensity PA in bouts ≥ 10 min for ≥ 20 min/day

Conclusions: In sedentary older adults, increasing moderate intensity PA to currently recommended levels does not result in favorable changes in LV morphology or performance over 12 weeks. More prolonged exposure, higher PA intensity, or earlier initiation of PA may be necessary to see benefits.

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1. Introduction

Sedentary aging leads to adverse structural adaptations of the heart and circulatory system. These changes include increased arterial elastance, impaired left ventricular diastolic relaxation and compliance, and increased left ventricular systolic elastance [1]. While the coupling relationship of ventricular and arterial compliance is closely maintained with matching increases in both physiological attributes, the changes

leave sedentary older adults at greater risk for cardiac ischemia and heart failure [2,3].

Interestingly, life-long endurance physical activity is associated with significant mitigation of age-associated declines in left ventricular performance and arterial compliance [4]. However, whether increasing moderate intensity PA (3–6 metabolic equivalents, METs) to currently promulgated goal levels in older adults can reverse this adverse ventricular and arterial remodeling is unclear. In the context of a 12 week randomized control trial targeting an activity goal of 10,000 steps/day, we recently showed that increasing moderate intensity PA can reverse age-related vascular endothelial dysfunction in previously sedentary older adults [2]. In the context of this study, we evaluated the effects of increasing moderate intensity PA on cardiovascular performance profile in older sedentary adults.

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2. Methods

2.1. Subjects

114 sedentary older adults (ages ≥ 50 and ≤ 80 years of age) were recruited for this study based at the Medical College of Wisconsin (Milwaukee, WI) between 2010 and 2012. The methods and design of the randomized clinical trial have been previously described in detail [2]. Briefly, screened participants aged ≥ 50 years old who averaged ≤ 8000 steps/day (measured by an Omron HJ-720ITC pedometer (Omron, Lake Forest, IL)) over 1 week and met all other previously reported inclusion criteria were randomized. We excluded individuals with uncontrolled hypertension ($\geq 160/100$), recent myocardial infarction (within 1 month of enrollment), angina, clinical evidence of heart failure or documented left ventricular ejection fraction of $\leq 45\%$, renal insufficiency, liver dysfunction, active malignancy, or cognitive impairment. Only 4 participants reported a prior history of coronary artery disease, and all had normal ejection fractions without wall motion abnormalities. The study protocol was approved by the Medical College of Wisconsin's Institutional Research Board, and all participants provided written informed consent. Subjects were randomized into 1 of 3 intervention groups: 1) control, 2) pedometer only with verbal instructions to reach 10,000 steps by increasing step count by 10%/week and 3) a pedometer with access to an interactive website designed to teach ways of integrating moderate intensity physical activity into daily life with the same step count goal as group 2 as previously described [2].

2.2. Study visit procedures (prior to and following the 12 week intervention period)

2.2.1. General procedures

All subjects fasted overnight prior to their study visit. Height and weight were measured in metric units. Waist circumference was measured at the level of the umbilicus while standing. Heart rate and blood pressure (BP) were measured in triplicate and averaged.

2.2.2. Physical activity procedures

PA was measured and intensity was categorized as previously described [2]. Briefly, step count and accelerometry data were collected using Omron HJ-720ITC and ActiGraph GT3X (ActiGraph GTX3, ActiGraph, Pensacola, FL), for 1 week at the time of enrollment and during the final week of the 12 week intervention period.

For the accelerometer data, time blocks of ≥ 60 min of continuous activity count of zero was removed from analysis. This was considered time when the monitor was not worn. To be considered valid for a given day, we required the accelerometer to be worn for a minimum of 600 min/day. Participants with ≥ 4 days of valid accelerometer data were included in the analysis. For each minute, the accelerometer data was coded as sedentary activity (0–100 counts, < 1.5 MET intensity), light activity (101–1951 counts, 1.5–3 METs), moderate intensity activity (1952–5924 counts, 3–6 METs), or vigorous activity (> 5925 counts, > 6 METs) [5]. Further, a continuous bout of moderate or vigorous intensity PA was defined as ≥ 10 consecutive minutes at the aforementioned PA intensity.

2.3. Transthoracic echocardiogram

Complete resting transthoracic echocardiograms were performed following an overnight fast and in resting state by a registered cardiac sonographer at baseline and 12 weeks. All images were obtained using a Vivid 7 (General Electric, Milwaukee, WI), with an M3S sector transducer (1.5–4.6 MHz) and obtained by a registered cardiac sonographer experienced in echocardiographic imaging. All image analyses were performed off line using standard GE software (EchoPAC). All quantitative measurements were made in triplicate and averaged for

the final reported value. The images were obtained from the parasternal, apical, and subcostal windows by an established protocol. The parasternal view provided a full standard view, depth reduced view to evaluate the left ventricular (LV) size and wall thickness, and the zoom in view to evaluate the left ventricular outflow tract (LVOT) for measuring the LVOT diameter. The apical view provided a full standard 2, 3 and 4 chamber view and a depth reduced 2 and 4 chamber view to evaluate the LV ejection fraction (EF) using a modified Simpson's biplane method. Zoomed 4-chamber apical views were obtained to measure medial and lateral mitral annular velocities using tissue Doppler imaging. Apical 2, 3, and 4 chamber views were obtained for longitudinal strain imaging and analysis. Five consecutive ECG gated cardiac cycles were acquired with a frame rate ≥ 64 frames per second (fps). Images were stored digitally and then transferred to an EchoPac (GE Healthcare, Milwaukee, WI) system for offline 2D and speckle-tracking analyses. Average strain rate for each wall segment as well as a global longitudinal strain were measured. Pulse and continuous wave Doppler images obtained in the 3 and 5 chamber views were obtained for measurements of cardiac output and the myocardial performance index. All valves underwent Doppler interrogation to assess for the presence and severity of any occult valvular disease.

From this set of images, we measured arterial elastance (E_a) ($0.9 \times$ systolic blood pressure) / (stroke volume \times body surface area) and left ventricular elastance (E_{es}), and LV systolic compliance as previously described [6,7]. Myocardial performance index was also calculated as previously described [8–11].

2.4. Statistical analysis

All analyses were performed using SigmaStat 12.0 and/or SPSS 21.0. The baseline characteristics were compared by one-way ANOVA or χ^2 as appropriate. Correlations between step count, cardiovascular performance measures, and minutes of PA were calculated using Pearson's r . Anthropomorphic measurements, measurements of cardiovascular performance, step count, and time spent in differing levels of PA intensity were compared using general linear models with time (measurements pre- and post-12 week intervention period) as the within subjects factor and randomization assignment as the between subjects factor. Group by time interactions were analyzed for all outcomes. Post hoc testing was performed using Tukey HSD as appropriate. P values of < 0.05 are considered statistically significant. The randomized clinical trial in this study is powered based on the primary outcomes of changes in endothelial function by FMD% and arterial stiffness by PWV and the augmentation index [2]. However, based on prior work with respect to E' [9,12], our study with 26 subjects per group has greater than 90% power to detect a 1.5 cm/s increase in E' with our intervention at $\alpha = 0.05$.

3. Results

3.1. Baseline demographics

As previously reported, a total of 107 of the enrolled 114 subjects completed the study [2]. The final 5 of the 107 subjects did not have echocardiograms performed due to study financial restraints, leaving a total of 102 subjects available for analyses. There were no significant differences between groups with respect to their sex, age, history of hypertension, smoking status, and history of diabetes. There were also no baseline differences in waist circumference, blood pressure, body mass index, and heart rate (Table 1).

3.2. Changes in baseline demographics by intervention group

Over the 12 week study intervention period, weight ($P = 0.01$), BMI ($P = 0.003$), and waist circumference ($P = 0.009$) decreased for the entire population but did not differ by group assignment. No difference

Table 1
Baseline demographics.

	Control (N = 39)		Pedometer only (N = 35)		Pedometer + website (N = 28)		P-value
	Baseline	Week 12	Baseline	Week 12	Baseline	Week 12	
Age (years)	62 ± 6	–	64 ± 7	–	63 ± 8	–	0.39
Sex (% female)	74.4	–	62.9	–	57.1	–	0.31
History of diabetes (%)	0	–	0	–	3.6	–	0.26
History of hypertension (%)	30.8	–	28.6	–	39.3	–	0.64
Smoking status (% current)	10.3	–	5.7	–	7.1	–	0.77
Smoking status (% past)	25.6	–	31.4	–	39.3	–	0.77
	Control (N = 39)		Pedometer only (N = 35)		Pedometer + website (N = 28)		P-values (time effect/time × group interaction)
	Baseline	Week 12	Baseline	Week 12	Baseline	Week 12	
Weight (kg)	80.1 ± 16.5	79.4 ± 16.7	83.0 ± 17.4	82.1 ± 17.8	88.0 ± 18.5	86.8 ± 19.2	0.02/0.77
Body mass index (kg/m ²)	29.8 ± 6.4	29.1 ± 6.3	28.9 ± 5.0	28.6 ± 5.34	29.8 ± 5.7	29.2 ± 6.1	0.003/0.65
Waist circumference (cm)	99.5 ± 14.0	99.0 ± 14.2	99.5 ± 13.0	98.7 ± 13.1	102.7 ± 14.1	100.8 ± 13.3	0.054/0.02
Systolic blood pressure	130 ± 13	130 ± 16	130 ± 15	127 ± 16	131 ± 14	129 ± 14	0.20/0.54
Diastolic blood pressure	70 ± 9	70 ± 10	68 ± 8	69 ± 8	70 ± 6	70 ± 8	0.67/0.87
Heart rate (bpm)	64 ± 9	65 ± 9	63 ± 9	62 ± 10	63 ± 9	61 ± 8	0.24/0.10

in heart rate or blood pressure, over the 12 week period within or between study groups, was found (Table 1).

3.3. Changes in step count and physical activity by randomization group

Step count and accelerometer results are reported in Table 2. A total of 9 subjects were excluded due to inadequate pedometer or accelerometer measurements based on a priori described quality parameters for these measures. No significant differences in baseline step count between activity groups at baseline (P = 0.71). Average step count significantly increased in groups 2 and 3 (5136 ± 1554 to 9596 ± 3907 and 5474 ± 1512 to 8167 ± 3111 steps in groups 2 and 3, respectively, P < 0.001 for the time × group interaction, P < 0.001 within groups 2 and 3) with no change in step count for group 1 (4931 ± 1667 to 5410 ± 2410 steps, P = 0.12). There was no significant difference between the 12 week step counts of groups 2 and 3 (P = 0.16). Overall, 5%, 50%, and 31% of subjects achieved ≥ 10,000 steps/day by week 12 in groups 1, 2, and 3, respectively. Combining the 2 intervention groups (2 and 3), 43% (27/62) of individuals achieved 10,000 steps by week 12.

Detailed accelerometer data has been previously published [2]. Briefly, the accelerometer showed no differences in the total time observed within groups over the 12 week period (Table 2). Average daily moderate intensity physical activity (MPA) increased between weeks 1 and 12 (P < 0.001). MPA at baseline between activity groups (P = 0.60) showed no differences. There was a significant increase in MPA in groups 2 (19 ± 11 to 48 ± 31 min, P < 0.001) and 3 (19 ± 4 to 35 ± 11, P = 0.001) but not in group 1 (16 ± 10 to 17 ± 14 min,

P = 0.86). The amount of MPA between groups 2 and 3 at the conclusion of the intervention period was not significantly different (P = 0.08). There were no differences in MPA performed in bouts at baseline (P = 0.38). MPA performed in bouts significantly increased within both group 2 (7 ± 8 to 14 ± 10 min, P < 0.001) and group 3 (7 ± 9 to 27 ± 21 min, P < 0.001), but not group 1 (4 ± 8 to 4 ± 8, P = 0.71). The time spent in MPA bout activity was significantly higher in groups 2 and 3 at week 12 compared to group 1 (P = 0.01), and was significantly higher in group 3 than group 2 at week 12 (P = 0.005).

3.4. Changes in echocardiographic measurements by randomization cardiovascular and vascular measures by group

Echocardiographic parameters by study group assignment are reported in Table 3. The echocardiographic measurements showed a significant decrease in septal wall thickness for the entire cohort (P = 0.002) over time with no differences between groups (P = 0.237). Both LV end-diastolic volume and end-systolic volume tended to increase for the entire population (P = 0.002, P = 0.037) over the 12 week period without between group differences.

LV ventricular systolic elastance (E_{es}) did not significantly change over the study period. While both arterial elastance and ventriculo-vascular coupling (E_a/E_{es}) and arterial elastance showed significant decreases for the entire study group over 12 weeks (P = 0.033), neither parameter significantly changed within the study groups. All other measures of cardiovascular performance and LV systolic and diastolic

Table 2
Step count and physical activity data by study group.

	Control N = 39 (step counts) N = 34 (accelerometry)		Pedometer only N = 35 (step count) N = 31 (accelerometry)		Pedometer + website N = 27 (step count) N = 27 (accelerometry)		P-values (time effect)	P-values (time × group interaction)
	Baseline	Week 12	Baseline	Week 12	Baseline	Week 12		
Average step count	4841 ± 1665	5142 ± 2143	5168 ± 1568	9673 ± 3937	5483 ± 1546	8211 ± 3297	<0.001	<0.001
Average minutes observed/day	908 ± 99	889 ± 75	934 ± 112	930 ± 121	944 ± 93	944 ± 133	0.48	0.75
Average moderate intensity activity minutes (3–6 METs)	16 ± 10	17 ± 14	19 ± 11	49 ± 31	20 ± 14	36 ± 24	<0.001	<0.001
Average moderate intensity in bouts	4 ± 8	4 ± 8	7 ± 8	14 ± 10	6 ± 9	27 ± 21	<0.001	<0.001
Subjects achieving ≥ 10,000 steps	0	0	0	18	0	9	–	<0.001
Subjects achieving ≥ 20 min/day of MPA in bouts	2	3	2	12	2	16	–	<0.001
Subjects achieving ≥ 30 min total of MPA	5	6	4	20	5	15	–	0.001

Table 3
Baseline ventricular–vascular function by study group.

	Group 1 (N = 39)		Group 2 (N = 35)		Group 3 (N = 28)		P-values (time effect)	P-values (time × group interaction)
	Baseline	Week 12	Baseline	Week 12	Baseline	Week 12		
Septal wall thickness (cm)	1.0 ± 0.2	0.9 ± 0.2	0.9 ± 0.2	0.9 ± 0.2	1.0 ± 0.2	1.0 ± 0.3	0.002	0.24
Posterior wall thickness (cm)	1.0 ± 0.1	1.0 ± 0.2	1.0 ± 0.2	1.0 ± 0.2	1.1 ± 0.2	1.1 ± 0.2	0.57	0.73
LV end diastolic dimension (cm)	4.3 ± 0.5	4.4 ± 0.5	4.5 ± 0.5	4.5 ± 0.5	4.5 ± 0.5	4.5 ± 0.5	0.08	0.30
LV end systolic dimension (cm)	2.8 ± 0.6	2.9 ± 0.5	3.0 ± 0.6	2.9 ± 0.6	3.0 ± 0.5	3.0 ± 0.5	0.55	0.64
Mean LV end diastolic volume (biplane)	84.6 ± 22.6	91.5 ± 22.1	93.0 ± 21.7	94.7 ± 22.3	91.6 ± 18.7	97.5 ± 21.3	0.002	0.32
Mean LV end systolic volume (biplane)	35.4 ± 12.4	37.8 ± 10.6	37.0 ± 10.1	38.2 ± 10.7	36.9 ± 8.2	39.1 ± 12.0	0.04	0.83
LVEF Simpsons biplane (%)	56.3 ± 7.6	56.3 ± 6.5	57.7 ± 6.3	58.7 ± 6.6	57.2 ± 4.7	57.7 ± 7.7	0.54	0.85
LV outflow tract diameter (mm)	1.9 ± 0.2	1.9 ± 0.3	1.9 ± 0.2	2.0 ± 0.3	2.0 ± 0.3	2.0 ± 0.3	0.11	0.68
Mitral E wave velocity (cm/s)	7.2 ± 1.6	7.2 ± 1.5	7.0 ± 2.0	7.1 ± 2.0	7.0 ± 2.0	7.0 ± 1.4	0.74	0.81
Mitral A wave velocity (cm/s)	6.0 ± 2.0	6.2 ± 2.2	5.6 ± 1.8	6.0 ± 1.8	5.8 ± 1.7	5.9 ± 1.9	0.10	0.74
Septal e (cm/s)	6.0 ± 1.5	5.7 ± 1.7	6.1 ± 2.1	6.2 ± 1.7	6.0 ± 1.5	6.0 ± 1.6	0.62	0.69
Lateral e (cm/s)	6.7 ± 1.8	6.8 ± 1.7	7.2 ± 2.1	7.1 ± 2.3	7.0 ± 1.9	6.8 ± 1.8	0.67	0.67
Isovolumetric relaxation time (IVRT) (ms)	83.4 ± 5.7	83.8 ± 6.4	82.0 ± 5.7	82.5 ± 6.3	83.2 ± 6.1	83.2 ± 5.3	0.68	0.95
Isovolumetric contraction time (IVCT) (ms)	46.5 ± 7.8	45.0 ± 8.5	44.7 ± 7.8	44.0 ± 6.9	45.6 ± 7.1	44.7 ± 8.1	0.18	0.89
Ejection time ms	309.7 ± 30.4	317.0 ± 26.7	313.6 ± 31.9	320.0 ± 30.5	321.4 ± 24.9	319.3 ± 24.1	0.09	0.20
LV outflow tract VTI	21.1 ± 3.7	21.6 ± 3.5	21.4 ± 3.9	21.8 ± 2.9	22.2 ± 3.4	22.1 ± 3.5	0.39	0.69
Aortic VTI	27.5 ± 5.5	29.1 ± 5.5	28.2 ± 6.5	29.1 ± 6.3	28.5 ± 6.6	28.4 ± 6.3	0.05	0.22
Mean stroke volume (SV) (ml/m ²)	49.2 ± 12.7	53.7 ± 13.4	56.0 ± 13.8	56.5 ± 13.3	54.7 ± 12.9	58.4 ± 12.8	0.006	0.24
Stroke volume Simpsons (ml/m ²)	48.8 ± 12.7	54.5 ± 13.3	55.6 ± 13.7	57.4 ± 12.9	54.4 ± 12.8	58.9 ± 13.3	<0.001	0.31
Stroke volume VTI (ml/m ²)	40.1 ± 7.7	41.9 ± 8.0	41.2 ± 8.0	43.8 ± 9.3	43.4 ± 8.3	43.8 ± 10.4	0.044	0.57
LV mass index (g/m ²)	79.0 ± 20.7	76.5 ± 25.0	77.9 ± 15.6	76.8 ± 17.0	83.1 ± 22.0	81.8 ± 22.2	0.32	0.93
E/A	1.3 ± 0.4	1.3 ± 0.4	1.3 ± 0.5	1.3 ± 0.4	1.2 ± 0.3	1.3 ± 0.4	0.07	0.11
LV systolic elastance (E _{es})	3.3 ± 0.9	3.1 ± 0.7	3.0 ± 0.5	3.0 ± 0.6	3.1 ± 0.8	3.0 ± 0.6	0.47	0.58
Arterial elastance (normalized) (mm hg/ml)	1.37 ± 0.47	1.22 ± 0.38	1.15 ± 0.37	1.12 ± 0.37	1.13 ± 0.33	1.04 ± 0.29	0.002	0.19
E _a /E _{es}	0.41 ± 0.08	0.40 ± 0.09	0.38 ± 0.08	0.37 ± 0.08	0.37 ± 0.08	0.36 ± 0.07	0.033	0.55
Mitral annular early diastolic velocity (average septal/lateral)	6.3 ± 1.5	6.3 ± 1.5	6.7 ± 2.0	6.4 ± 1.8	6.5 ± 1.6	6.4 ± 1.6	0.57	0.93
Ratio of mitral passive inflow velocity and e' (E/e')	11.9 ± 3.2	12.2 ± 4.1	11.3 ± 5.0	11.5 ± 4.6	10.9 ± 3.2	11.0 ± 2.6	0.42	0.95
Global longitudinal strain (GLS)	−17.0 ± 3.6	−17.5 ± 4.3	−17.8 ± 3.1	−18.1 ± 2.2	−17.3 ± 3.8	−16.1 ± 4.9	0.74	0.12
Myocardial performance index (MPI)	0.30 ± 0.06	0.29 ± 0.07	0.28 ± 0.05	0.28 ± 0.05	0.29 ± 0.05	0.28 ± 0.05	0.65	0.80

function, and global longitudinal strain showed no significant difference either over time or within study groups.

3.5. Changes in echocardiographic parameters and ventriculo-vascular coupling based on achievement of 1) 10,000 steps/day threshold, 2) ≥20 min/day average of MPA in bouts ≥10 min in length, and 3) 30 min/day MPA average

Data stratifying the study population based on achieving each of the above activity thresholds are presented in Table 4. Overall, no significant within group changes were seen over time for our measurements of diastolic function, E_a, E_{es}, E_a/E_{es}, or myocardial performance with the exception of mitral E/A ratio for those achieving 30 min/day of MPA by the end of the study (P = 0.02 for the interaction of time × group). This is primarily driven by a decreased E/A ratio in those who did not achieve 30 min/day of MPM (P = 0.01). There was no change in E/A ratio for those who did achieve this goal (P = 0.09).

3.6. Correlations of age and physical activity with echocardiographic performance measures

There were no significant associations between step count, minutes of MPA, minutes of MPA in bouts and cardiovascular performance measures. Age and measures of cardiovascular performance that have significant correlations at baseline were E_{es} (r = 0.27, P = 0.006), E_a (r = 0.22, P = 0.03), mitral annular early diastolic velocity (average septal and lateral) (r = 0.48, P < 0.001), E/e' (r = 0.32, P = 0.001), and E/A ratio (r = 0.37, P < 0.001).

4. Discussion

In contrast to our prior work showing a favorable impact of increasing MPA on dynamic vascular endothelial function in humans, our current data demonstrate that improvement in MPA after a 12 week intervention in healthy, free-living sedentary adults aged ≥50 does not significantly impact LV systolic performance or diastolic function, arterial elastance, or ventricular elastance. Our data significantly extends the body of heterogeneous, largely cross-sectional data available comparing the LV performance, LV compliance, and arterial elastance of younger individuals to older sedentary individuals and older life-long trained athletes by demonstrating that commonly advocated public health recommendations to improve physical activity by achieving 10,000 steps/day [13,14] or 30 min MPA/day [15] are not associated with near-term improvement in LV systolic performance or LV diastolic function [4,16–20]. Combined with prior data, our study suggests that reversing sedentary aging-related LV remodeling and increased arterial elastance requires either 1) a more prolonged exposure to MPA or a greater intensity of PA or 2) earlier intervention to reverse the impact of sedentary aging. Further, these data suggest that the favorable cardiovascular impact of MPA in older adults may relate in larger portion to improvements in dynamic vascular endothelial function as opposed to LV reverse remodeling.

Aging is known to impact the structure and function of the cardiovascular system, and age-related remodeling appears to be secondary to both alterations in cardiac myocyte phenotype as well as increased collagen deposition within an aging myocardium [21].

LV early diastolic filling rates progressively decrease after age 20 and by 80 years old are reduced by up to 50% [21]. Impaired LV diastolic function occurring with age often manifests echocardiographically

Table 4
Cardiovascular performance based on physical activity regimen.

	Bout < 20 min (N = 62)		Bout ≥ 20 min (N = 30)		P-values (time effect)	P-values (time × group interaction)
	Baseline	Week 12	Baseline	Week 12		
LV systolic elastance (E_{es})	3.2 ± 0.8	3.0 ± 0.7	3.0 ± 0.6	3.0 ± 0.6	0.28	0.17
E_a over E_{es}	0.39 ± 0.08	0.38 ± 0.09	0.38 ± 0.08	0.37 ± 0.06	0.10	0.72
Arterial elastance (normalized) (mm Hg/ml)	1.25 ± 0.42	1.15 ± 0.39	1.14 ± 0.37	1.11 ± 0.30	0.03	0.27
Mitral annular early diastolic velocity (average septal/lateral) ^a	6.3 ± 1.5	6.3 ± 1.5	6.7 ± 2.0	6.4 ± 1.8	0.57	0.93
E/A	1.3 ± 0.5	1.2 ± 0.4	1.3 ± 0.3	1.4 ± 0.4	0.91	0.018
Ratio of mitral passive inflow velocity and E'^{b}	11.5 ± 3.3	11.7 ± 4.0	10.7 ± 4.9	10.9 ± 3.7	0.41	0.93
Myocardial performance index	0.29 ± 0.06	0.29 ± 0.06	0.28 ± 0.05	0.28 ± 0.05	0.88	0.82
	10,000 < steps (N = 75)		10,000 ≥ 20 steps (N = 27)			
LV systolic elastance	3.1 ± 0.7	3.0 ± 0.6	3.1 ± 0.8	3.0 ± 0.7	0.22	0.53
E_a over E_{es}	0.39 ± 0.08	0.38 ± 0.08	0.38 ± 0.08	0.37 ± 0.07	0.05	0.55
Arterial elastance (normalized)	1.25 ± 0.42	1.15 ± 0.36	1.17 ± 0.40	1.12 ± 0.35	0.02	0.37
Mitral annular early diastolic velocity (average septal/lateral) ^c	6.5 ± 1.7	6.4 ± 1.6	6.5 ± 1.9	6.5 ± 1.8	0.71	0.81
E/A	1.3 ± 0.4	1.3 ± 0.4	1.2 ± 0.4	1.2 ± 0.4	0.62	0.62
Ratio of mitral passive inflow velocity and E'^{d}	11.3 ± 3.2	11.5 ± 3.7	12.0 ± 5.5	12.0 ± 4.8	0.55	0.75
Myocardial performance index	0.29 ± 0.06	0.29 ± 0.06	0.29 ± 0.05	0.28 ± 0.05	0.70	0.95
	MPA < 30 min (N = 51)		MPA ≥ 30 min (N = 40)			
LV systolic elastance	3.2 ± 0.8	3.0 ± 0.7	2.9 ± 0.6	3.0 ± 0.6	0.14	0.09
E_a over E_{es}	0.39 ± 0.09	0.39 ± 0.09	0.38 ± 0.07	0.37 ± 0.06	0.10	0.60
Arterial elastance (normalized)	1.28 ± 0.44	1.18 ± 0.40	1.12 ± 0.34	1.08 ± 0.30	0.01	0.25
Mitral annular early diastolic velocity (average septal/lateral) ^e	6.4 ± 1.7	6.3 ± 1.7	6.6 ± 1.8	6.7 ± 1.7	0.78	0.52
E/A	1.4 ± 0.5	1.2 ± 0.4	1.2 ± 0.3	1.3 ± 0.4	0.65	0.003
Ratio of mitral passive inflow velocity and E'^{f}	11.6 ± 3.5	11.9 ± 4.2	10.9 ± 4.3	10.9 ± 3.6	0.40	0.54
Myocardial performance index	0.29 ± 0.06	0.29 ± 0.07	0.29 ± 0.05	0.29 ± 0.05	0.83	0.77

Bold values indicate significance at $P < 0.05$.

^a N = 61 and 30, respectively

^b N = 61 and 29, respectively

^c N = 74 and 27, respectively

^d N = 74 and 26, respectively

^e N = 50 and 41, respectively

^f N = 50 and 40, respectively

with reduced early diastolic relaxation velocity of the mitral annulus (e'), reduced mitral passive to active diastolic inflow velocities (E/A ratio) in the absence of increased left atrial pressure, and prolonged isovolumetric relaxation time (IVRT) in the absence of increased left atrial pressure [10, 22]. Consistent with this prior literature, our study population shows impaired e' velocities' velocity (E') [9,10]. Further, the correlations between diastolic parameters, E_a , E_{es} and increasing age in our study population are entirely consistent with sedentary aging-related changes in these parameters.

However, while LV compliance is favorably impacted by exercise training in young adults [23], the impact of exercise training and physical activity on age-related deterioration of LV compliance remains unclear. Cross-sectional data suggest that echocardiographic parameters of LV diastolic relaxation and compliance, including mitral E/A ratio, IVRT, and LV inflow propagation velocity, are not fully preserved by lifelong exercise training, while mitral annular tissue velocities could be favorably impacted [12,17,20]. Invasive measurements suggest that LV compliance is favorably preserved in lifelong trained individuals compared to age-matched controls [4]. Differences between these studies may relate to differences in study populations, the heterogeneity of the durations and compositions of training programs of individuals enrolled, and differences in measure of LV diastolic performance. One non-randomized study of nine older adults employing a year-long vigorous aerobic training program failed to demonstrate a significant impact on age-related impairment of LV compliance [16]. Our study extends these data by showing, in the setting of a randomized study, that increasing physical activity in previously sedentary older adults to currently promulgated goal PA levels does not reverse aging related LV changes, suggesting several potential possibilities: 1) improvements in this population may require greater PA intensity and/or a greater duration of training, and 2) LV remodeling in sedentary older adults may have limited reversibility secondary to age-related LV remodeling

involving potentially more immutable alterations in interstitial structure [16,24]. Further interventional studies are necessary in this area to better determine whether PA of any type, duration, and intensity can reverse age-related deterioration of LV compliance.

While arterial elastance (E_a) increases with age and is associated with increased cardiovascular risk [3], limited data are available on the impact of exercise training on E_a . In the previously cited small interventional study, E_a was favorably reduced by 1 year of vigorous exercise training [16]. Our data show no significant impact of moderate intensity PA at currently recommended levels of activity of E_a over a shorter intervention period. Taken together, these data suggest that either a longer duration of moderate intensity PA is required to reduce age-related increases in arterial elastance or vigorous intensities are required. Further interventional studies will be needed to better determine the amount and intensity of PA needed for these favorable effects.

Combining prior findings with our current work, available evidence suggests that the cardiovascular benefits of physical activity in older adults are derived in larger part due to improvements in dynamic vascular regulation and structure rather than alterations of left ventricular performance. This concept is buoyed by findings by our laboratory and others that exercise training in previously sedentary older adults improves vascular endothelial function and reduces vascular stiffness while, as reviewed above, the majority of data regarding the impact of exercise training in previously sedentary older adults on LV specific measures have been underwhelming [2,16,25]. The lack of impact of MPA in the current study on measures of arterial stiffness suggests that MPA at the level and dose achieved was insufficient to reverse age-related vascular remodeling rather than negating prior encouraging findings.

Our study has some limitations. The use of non-invasive measures of early diastolic filling aided the feasibility of this trial, but invasive measures of diastolic function such as rate of LV pressure decline or LV filling

pressures may have allowed greater sensitivity to the impact of PA on LV performance. A more prolonged exposure to PA may have greater impact on both arterial and vascular remodeling. Our study population included no subjects with active ischemic heart disease or LV systolic dysfunction. Our results cannot be generalized to those with active ischemic disease or LV systolic dysfunction. Balanced against these limitations are the interventional nature of our data and its focus on the impact of currently promulgated PA duration and intensity on arterial and ventricular elastance.

In conclusion, our data suggest that increasing moderate intensity physical activity to currently recommended levels over 12 weeks does not significantly impact LV or arterial compliance in previously sedentary older adults. Combined with prior cross-sectional and limited interventional data, our data suggest that the favorable cardiovascular impact of habitual physical activity in older adults who have recently begun an activity regimen may be related in larger portion to improvements in dynamic vascular function rather than reverse remodeling of the left ventricle. Further interventional work is necessary to better determine the dosing of physical activity that maximizes its cardiovascular benefits in older adults.

Conflict of interest

We have no conflicts of interest to report with full disclosure regarding any relationship to industry.

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