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Differential Effects Of Continuous Versus Discontinuous Aerobic Training On Blood Pressure And Hemodynamics

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Abstract

The purpose of this study was to compare the hemodynamic, arterial stiffness, and blood flow changes after 4 weeks of either continuous or discontinuous aerobic exercise in adults. Forty-seven subjects between the ages of 18 and 57 were recruited for 1 month of either continuous aerobic treadmill work for 30 minutes at 70% max heart rate or 3 bouts of 10 minutes of exercise at 70% of max heart rate with two 10 minutes break periods in between, totaling 30 minutes of aerobic work. After exercise, both continuous (CON) and discontinuous (DIS) groups demonstrated a significant improvement in maximal oxygen uptake (V[Combining Dot Above]O2max, CON 35.39 ± 1.99 to 38.19 ± 2.03; DIS 36.18 ± 1.82 to 39.33 ± 1.75), heart rate maximum (CON 183.5 ± 3.11 to 187.17 ± 3.06; DIS 179.06 ± 2.75 to 182 ± 2.61), decreases in systolic blood pressure (CON 119 ± 1.82 to 115.11 ± 1.50; DIS 117.44 ± 1.90 to 112.67 ± 1.66), diastolic blood pressure (CON 72.56 ± 1.65 to 70.56 ± 1.06; DIS 71.56 ± 1.59 to 69.56 ± 1.43), augmentation index (CON 17.17 ± 2.17 to 14.9 ± 1.92; DIS 19.71 ± 2.66 to 13.91 ± 2.46), central pulse wave velocity (CON 8.29 ± 0.32 to 6.92 ± 0.21; DIS 7.85 ± 0.30 to 6.83 ± 0.29), peripheral pulse wave velocity (CON 9.49 ± 0.35 to 7.72 ± 0.38; DIS 9.11 ± 0.37 to 7.58 ± 0.47), and significant increases in average forearm blood flow (CON 4.06 ± 0.12 to 4.34 ± 0.136; DIS 4.26 ± 0.18 to 4.53 ± 0.15), peak forearm blood flow (FBF) after reactive hyperemia (CON 28.45 ± 0.094 to 29.96 ± 0.45; DIS 29.29 ± 0.46 to 30.6 ± 0.38), area under the curve (AUC) of FBF (CON 28.65 ± 1.77 to 30.4 ± 1.08; DIS 30.52 ± 1.9 to 31.67 ± 1.44), and AUC peak FBF after reactive hyperemia (CON 222.3 ± 5.68 to 231.95 ± 4.42; DIS 230.81 ± 6.91 to 237.19 ± 5.39). These data suggest that for healthy people either 4 weeks of continuous or discontinuous aerobic training is effective in improving measures of fitness and vascular health.

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Differential Effects of Continuous Versus Discontinuous Aerobic Training on Blood Pressure and Hemodynamics

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Abstract

Landram, MJ, Utter, AC, Baldari, C, Guidetti, L, McAnulty, SR, and Collier, SR. Differential effects of continuous versus discontinuous aerobic training on blood pressure and hemodynamics. *J Strength Cond Res* 32(1): 97–104, 2018—The purpose of this study was to compare the hemodynamic, arterial stiffness, and blood flow changes after 4 weeks of either continuous or discontinuous aerobic exercise in adults. Forty-seven subjects between the ages of 18 and 57 were recruited for 1 month of either continuous aerobic treadmill work for 30 minutes at 70% max heart rate or 3 bouts of 10 minutes of exercise at 70% of max heart rate with two 10 minutes break periods in between, totaling 30 minutes of aerobic work. After exercise, both continuous (CON) and discontinuous (DIS) groups demonstrated a significant improvement in maximal oxygen uptake ($\dot{V}O_2$max, CON 35.39 ± 1.99 to 38.19 ± 2.03; DIS 36.18 ± 1.82 to 39.33 ± 1.75), heart rate maximum (CON 183.5 ± 3.11 to 187.17 ± 3.06; DIS 179.06 ± 2.75 to 182 ± 2.61), decreases in systolic blood pressure (CON 119 ± 1.82 to 115.11 ± 1.50; DIS 117.44 ± 1.90 to 112.67 ± 1.66), diastolic blood pressure (CON 72.56 ± 1.65 to 70.56 ± 1.06; DIS 71.56 ± 1.59 to 69.56 ± 1.43), augmentation index (CON 17.17 ± 2.17 to 14.9 ± 1.92; DIS 19.71 ± 2.66 to 13.91 ± 2.46), central pulse wave velocity (CON 8.29 ± 0.32 to 6.92 ± 0.21; DIS 7.85 ± 0.30 to 6.83 ± 0.29), peripheral pulse wave velocity (CON 9.49 ± 0.35 to 7.72 ± 0.38; DIS 9.11 ± 0.37 to 7.58 ± 0.47), and significant increases in average forearm blood flow (CON 4.06 ± 0.12 to 4.34 ± 0.136; DIS 4.26 ± 0.18 to 4.53 ± 0.15), peak forearm blood flow (FBF) after reactive hyperemia (CON 28.45 ± 0.094 to 29.96 ± 0.45; DIS 29.29 ± 0.46 to 30.6 ± 0.38), area under the curve (AUC) of FBF (CON 28.65 ± 1.77 to 30.4 ± 1.08; DIS 30.52 ± 1.9 to 31.67 ± 1.44), and AUC peak FBF after reactive hyperemia (CON 222.3 ± 5.68 to 231.95 ± 4.42; DIS 230.81 ± 6.91 to 237.19 ± 5.39). These data suggest that for healthy people either 4 weeks of continuous or discontinuous aerobic training is effective in improving measures of fitness and vascular health.

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Key Words discontinuous exercise, continuous exercise, age, sex, blood flow

Introduction

Controlling blood pressure (BP) is an essential aspect of cardiovascular (CV) disease prevention (7). In the last decade, the National Health and Nutrition Survey has shown an increasing number of young adults who present with prehypertension (PHTN) (14), which raises concerns as even PHTN is found to be an independent risk factor for end organ damage and an indicator of adverse CV events (33). However, according to the report from the Joint National Committee on Prevention, Detection, Evaluation, and treatment of High Blood Pressure (7), PHTN is not directly categorized as a disease, and individuals with PHTN are not candidates for drug therapy. Because of this status, alternative therapies such as lifestyle modification through the inclusion of regular exercise are used most commonly to forestall the progression of PHTN to hypertension.

The current recommendation is that people with PHTN practice lifestyle modification that includes the addition of physical activity and exercise to control their BP. Regular aerobic exercise (AE) training has repeatedly been shown to reduce systolic BP and diastolic BP and is considered a *Class I, Level of Evidence A* recommendation for BP-lowering efficacy by the American Heart Association (5). These improvements can be seen in 4 or fewer weeks of training in prehypertensiveto stage-1 hypertensive when using moderate intensity continuous (CON) AE (8). Longitudinal studies evaluating chronic CON moderate intensity AE display systolic blood pressure and diastolic blood pressure (SBP and DBP) reductions of about 3.0 and 2.4 mm Hg, respectively, in normotensive individuals (5) and a more pronounced reduction in those with elevated BP (3). Nevertheless, there is still uncertainty regarding differing modes of AE and their effectiveness at improving BP. Though there is some consensus that multiple exercise modes of sufficient intensity will confer BP improvements, very few studies have examined different AE training modes with similar durations and intensities on blood flow and hemodynamics.

Most training studies conclude that traditional CON AE improves fitness and health through various pathways that include mitochondrial biogenesis and large artery distensibility (11,16,30) but with little improvement to the peripheral muscular arteries (16). Discontinuous (DIS) interval training has gained much interest in recent years as it has been suggested to confer similar cardiovascular remodeling and metabolic adaptations as traditional CON AE (6,27,32) but may not improve vascular function to the same extent (28). However, some studies suggest that DIS AE may be more beneficial than traditional CON AE when improving arterial stiffness (32). Although most studies focus on high intensity, low volume, interval (HIIT) training (28), few implement a like-intensity DIS AE training program similar to moderate intensities seen in traditional CON AE (23–25). The studies that attempt to control for intensity and duration differences have found that DIS AE results in a prolonged hypotensive phase after acute activity in prehypertensive and stage-1 hypertensive but not normotensive adults when compared with a single CON exercise session (20). With the available studies examining only the acute effects of exercise mode on hemodynamics and performance, there is a paucity of literature describing the chronic effects of CON vs. DIS AE training. And although some studies have examined both males and females (4) at high intensity AE, none have directly compared sexes at moderate intensities to determine differential hemodynamic changes resulting from exercise training.

The available literature describes HIIT and moderate intensity CON AE as being similar in result when examining subjects who have elevated BP but are not currently on medication (18). Both seem to confer a general reduction in BP, but different age groups respond at different rates. At moderate intensities, adolescents with elevated SBP respond after 12 weeks of training with significantly reduced resting BP, whereas in adults with similar characteristics the same results were accomplished in 16 weeks or only 8 weeks in young adults. This illuminates the differences in training time required to achieve significant BP changes in various populations. Indeed, it seems that age may play a role in how quickly training adaptations occur, regardless of training history or body composition (22). Park and colleagues (25) performed acute studies that demonstrate a comparative advantage of moderate intensity DIS over similar intensity CON regarding BP reductions. These findings are mirrored in studies examining the effect of the chronic HIIT vs. CON AE (18). However, direct comparisons between HIIT and CON are difficult as the adaptations to AE training occur in response to an increased energy demand of the working muscle and the manipulation of intensity and duration of work and rest intervals changes not only the metabolic demands but also the oxygen delivery (19). Additionally, a persistent issue in the available literature is the estimation of $\dot{V}O_2$max and HR_{max} (21). This discrepancy highlights the necessity for further studies to be conducted that examine differential effects of CON vs. DIS AE at similar workloads to evaluate the effectiveness at improving measures of fitness and health by improving risk factors. Generally, HIIT results in a much greater metabolic and oxygen delivery demand than CON steady state work in the working muscle. To better understand the specific effects of DIS AE on hemodynamics, arterial stiffness, and blood flow, matching the average intensity between training groups is essential. Even though studies (9) have better described BP alterations after exercise training, the underlying mechanisms are less well understood, with possible mitigating agents being increased arterial dispensability, an improved resting blood flow, and an increase in flow-mediated dilution of peripheral arteries.

Therefore, the purpose of this study was to compare the hemodynamic, arterial stiffness, and blood flow changes after 4 weeks of either CON or DIS AE in healthy adults while specifically focusing on differential effects between young vs. middle-aged males and females. We hypothesized that both types of moderate intensity AE would bestow similar changes to hemodynamics and arterial compliance by decreasing systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse wave velocity (PWV), and augmentation index (AIx) while increasing forearm blood flow (FBF) and reactive hyperemia (RH) but there would be no differences between groups.

Methods

Experimental Approach to the Problem

Subjects reported to the laboratory on fifteen separate occasions. Anthropometric measurements were taken on arrival to the laboratory, including body composition on the first, second, and fifteenth visits. After this, subjects sat in a quiet, environmentally controlled laboratory with an ambient temperature of 22–25° C for 15 minutes before BP readings were taken. Seated BP was taken manually by the same trained technician for each subject. After the acquisition of BP, subjects remained seated while a technician collected pulse wave analysis data from the radial artery on the left arm. Subjects then lay supine while pulse wave velocity was determined. Forearm blood flow and reactive hyperemia were also collected while the subject lay quietly. Finally, subjects performed a graded exercise test to maximum on a treadmill for acquisition of peak oxygen consumption ($\dot{V}O_2$peak) and maximal heart rate (HR_{max}).

After the first visit, subjects began a planned counterbalanced control period during which they continued normal routines for 4 weeks before returning to undergo an identically ordered battery of tests at visit 2. Subjects were instructed not to change their physical routines during this time. After the second visit to the laboratory, subjects began exercise training for the following 4 weeks (visits 3–14). Forty-eight hours after his or her final training session, each subject returned to the laboratory to complete the last round of testing, which was identical to the first 2 sessions.

Subjects

Forty-seven low-risk subjects (1) between the ages of 18 and 57 were recruited, 19 males, 28 females, separated into 2 age groups 18–25 for the younger and postmenopausal women and age matched men for the middle d group (40–57 years), from a university and rural community in North Carolina. Subjects were generally healthy nonsmokers with no history of heart disease, diagnosed hyperlipidemia, diabetes, or hypertension as identified in a health history questionnaire. Furthermore, subjects were told to refrain from taking over-the-counter medications or supplements, including anti-inflammatory agents or caffeine supplements, during the study. To reduce the influence of estrogen on cardiovascular measurements, all females who were not postmenopausal (history of >12 months of amenorrhea and not currently undergoing hormonal replacement therapy) were tested within the first 5 days of beginning menstruation.

The experimental procedures were explained to all subjects with informed consent obtained as approved by the Institutional Review Boards of Appalachian State University. After the provision of written consent where subjects signed informed consent documents, all subjects were randomly assigned to a continuous (CON) or discontinuous (DIS) training group (15 females, 8 males in CON and 13 females and 9 males in DIS).

Subjects

Weight was determined using a beam scale while height was measured using a stadiometer (402LB; Health-o-meter, Toledo, OH, USA) and recorded to the nearest 0.5 cm. Body composition was assessed using bioelectrical impedance (Tanita, Tokyo, Japan) and recorded to be 0.1%.

Hemodynamic Monitoring

Blood pressure was measured by the same trained exercise physiologist for each subject using standard sphygmomanometry after 15 minutes of quiet rest in the seated position. Systolic blood pressure and DBP were measured manually at the brachial artery after the resting period at the start of each testing session (visits 1, 2, and 15). American Heart Association Practices (Pickering, 2005) were adhered to, as the investigator used the first and fifth Korotkoff sounds for determination of BP. Heart rate was taken from the calculation of successive R-R intervals from the 3 lead electrocardiography (Sphygmacor, Sydney, Australia).

Arterial Pulse Wave Velocity and Aortic Blood Pressure Waveforms

Arterial pulse wave velocity and aortic blood pressure waveforms (PWV, ABPW, respectively) were measured and conducted in accordance with the guidelines set forth by the Clinical Application of Arterial Stiffness, Task Force III (34). An applanation tonometer (Sphygmacor, Sydney, Australia) was used to derive the ascending aortic blood pressure waveform and a range of central arterial indices. The Sphygmacor was used with a tonometer over a radial artery calibrated with a standard cuff blood pressure measurement as previously described. We obtained the pulse wave between (1) the left common carotid artery and the left femoral artery, and (2) the left femoral artery and the ipsilateral dorsalis pedis pulse. Distances from the (1) carotid sampling site to the midpoint of the manubrium sterni, (2) manubrium sternum to femoral artery, and (3) femoral artery to dorsalis pedis were measured between these points as straight lines with a tape measure. Pulse wave velocity was determined from the foot-to-foot flow wave velocity. The foot of the pressure wave was identified visually as the point of systolic upstroke. The time delay between a minimum of 15 simultaneously recorded flow waves was averaged. Pulse wave velocity was then calculated from the distances between measurement points and the measured time delay (Dt) between proximal and distal foot waveforms as follows: $PWV = D \cdot Dt^{-1}$ ($m \cdot s^{-1}$), where D is distance in meters and t is the time interval in seconds. Values obtained from carotid to femoral artery were taken as an index of central compliance while values obtained from the femoral to dorsalis pedis were taken as an index of peripheral compliance. All data were stored and analyzed off-line after completion of testing.

Blood Flow and Reactive Hyperemia

Forearm blood flow (FBF) and forearm RH was measured using mercury-filled strain-gauge plethysmography (EC-6; D.E. Hokanson, WA, USA), as previously described by our lab (9). Briefly, a cuff was placed around the upper right arm, a strain gauge around the widest part of the forearm, and an additional cuff around the wrist to occlude venous return of blood. Forearm blood flow was determined by the inflation of the arm cuff until ~50 mm Hg for 7 seconds, followed by 8 seconds deflation, during a 15-second cycle. This cycle was repeated 8 times. Once FBF was determined, the wrist cuff was inflated and held at 50 mm Hg above SBP for 5 minutes before release and resuming of normal measurement cycles as described above. The plethysmographic signal was captured by a digital recorder "on-line" during the test and saved for later analysis after data collection. An average of 3 cycles was used for analysis of FBF and will be expressed as milliliters per minute per 100 ml of forearm tissue.

Maximal Aerobic Capacity

Aerobic capacity was assessed using a customized treadmill protocol. Intensity began at 2.5 $min \cdot h^{-1}$ for 2 minutes and increased by 1 $min \cdot h^{-1}$ every 2 minutes until a comfortable

Table 1. Subject descriptive data (mean ± *SEM*).

	Continuous ($n = 23$)	Discontinuous ($n = 24$)
Age (y)	36.74 ± 2.86	37.16 ± 2.76
Height (cm)	171.4 ± 2.89	169.1 ± 3.1
Weight (kg)	71.6 ± 2.63	73.1 ± 2.57
Body fat (%) (pre/post)	26.62 ± 2.27/ 25.88 ± 2.22	22.6 ± 1.7/ 22.47 ± 1.72

pace was established. If additional intensity was required, the grade of the treadmill was increased (2%) at 2-minute intervals until volitional fatigue was reached or the criteria for successful maximal testing were established. The following criteria were used: (1) a plateau ($\Delta\dot{V}O_2 \leq 50$ ml·min^{-1} at $\dot{V}O_2$peak and the closest neighboring data point) in $\dot{V}O_2$, (2) maximal respiratory exchange ratio (RER) ≥ 1.1, and (3) maximal HR within 10 b·min^{-1} of the age-predicted maximum (220–age). Heart rate was recorded continuously during the protocol, and a minimum of 4 minutes into recovery, using a Polar Heart Rate Monitor (Polar Electro Inc., Woodbury, NY, USA). Expired gases were analyzed using a Parvo Medics TrueOne 2400 (Parvomedics, Utah, USA) breath-by-breath metabolic system and was smoothed as 15 seconds averages.

Exercise Training

Subjects were randomized after informed consent into one of 2 groups for the next 12 visits. The subjects were asked to complete an aerobic exercise bout on a treadmill at the at 70–75% of their predetermined HR_{max} for a continuous 30 minutes (CON group) or with a 10-minute rest period every 10 minutes (DIS group) of AE (1:1 work to rest ratio) for a total time of 30 minutes. Heart rate was measured using a Polar Heart Rate Monitor (Polar Electro Inc., Woodbury). The subjects returned to the lab 3 times per week for 4 weeks, with at least a day between visits (e.g., Monday–Wednesday–Friday). Subject had to attend all training sessions to stay in the study. If a subject were to miss a training session they must remake it within 24 hours of the original time. Failure to do so resulted in the subject being dropped from the study.

Statistical Analyses

Data were analyzed by SPSS v19 (SPSS, Chicago, IL, USA). Student's *t*-tests were used to determine significant differences for the descriptive variables between groups at randomization and then a one-way ANOVA was used to determine differences at experimental visit 1 vs. experimental visit 2. To determine if subjects' dependent variables at visit 1 and visit 2 were equal across the independent variable groups (CON vs. DIS), a 2-way analysis of covariance (ANCOVA) was used to co-vary for age (Young vs. Middle-age) and sex (Male vs. Female). No differences were found over the 4-week control period; therefore the first 2 time points were collapsed and averaged. A 2 × 2 (mode [Con vs. DIS] ×

Table 2. Hemodynamic characteristics (mean ± *SEM*).*

	Continuous, ($n = 23$: 8 males, 15 females)		Discontinuous, ($n = 24$: 9 males, 15 females)	
	Pre	Post	Pre	Post
$\dot{V}O_2$max (ml O_2·min^{-1}·kg^{-1})	35.39 ± 10.71	38.19 ± 10.49†	36.18 ± 7.7	39.33 ± 7.86†
HRmax (b·min^{-1})	183.5 ± 16.21	187.17 ± 14.32†	179.06 ± 14.62	182 ± 14.06†
SBP (mm Hg)	119 ± 5.22	115.11 ± 7.65‡	117.44 ± 7.79	112.67 ± 8.18‡
DBP (mm Hg)	72.56 ± 6.72	70.56 ± 5.03‡	71.56 ± 7.96	69.56 ± 7.21‡
AIx (%)	17.17 ± 9.3	14.9 ± 9.15†	19.71 ± 12.01	13.91 ± 11.07†
cPWV (m·s^{-1})	8.29 ± 1.21	6.92 ± 1.04†	7.85 ± 1.53	6.83 ± 1.48†
pPWV (m·s^{-1})	9.49 ± 1.49	7.72 ± 1.34†	9.11 ± 2	7.58 ± 1.95†
avgFBF (ml·min^{-1}·100 ml^{-1}·mm Hg^{-1})	4.06 ± 0.59	4.34 ± 0.6†	4.26 ± 0.76	4.53 ± 0.75†
peakBF (ml·min^{-1}·100 ml^{-1}·mm Hg^{-1})	28.45 ± 1.66	29.96 ± 2.16†	29.29 ± 1.18	30.6 ± 1.98†
AUC avgFBF (ml·min^{-1}·100 ml^{-1}·mm Hg^{-1})	28.65 ± 3.77	30.4 ± 4.08†	30.52 ± 5.9	31.67 ± 5.44†
AUC peakBF (ml·min^{-1}·100 ml^{-1}·mm Hg^{-1})	222.3 ± 15.68	231.95 ± 14.42†	230.81 ± 16.91	237.19 ± 15.39†

*$\dot{V}O_2$max= maximal oxygen uptake; HRmax= heart rate max ; SBP= systolic blood pressure; DBP= diastolic blood pressure; AIx= augmentation index; cPWV= central pulse wave velocity; pPWV= peripheral pulse wave velocity; avgFBF= average forearm blood flow; peakBF= peak blood flow; AUC avgFBF= area under curve FBF; AUC peakBF= area under curve peak BF.

†Significant pretraining to posttraining interaction $p < 0.001$.

‡Significant pre to post training interaction $p \leq 0.05$.

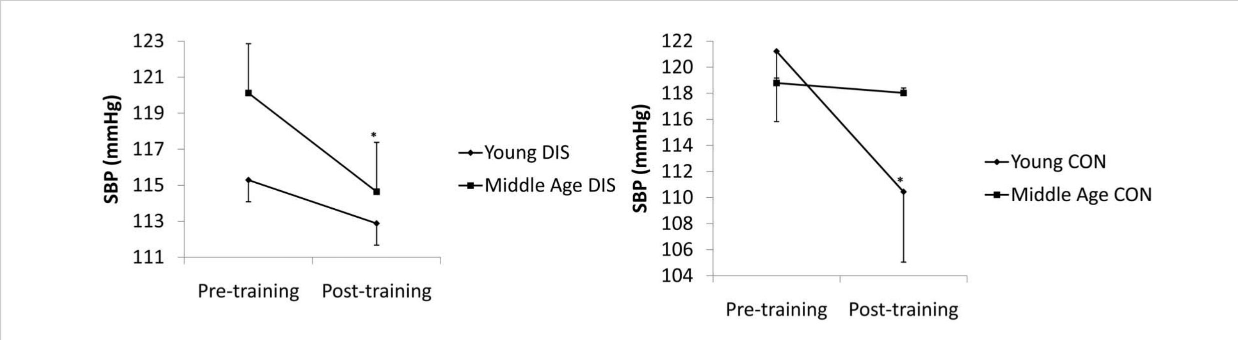

Figure 1. A) Changes in DIS group after training. MA DIS significantly decreased SBP compared with Y DIS. *$p < 0.05$ mean ± *SEM*. B) Changes in CON group after training. Y CON significantly decreased SBP compared with MA CON. *$p < 0.05$ mean ± *SEM*. A) DIS, discontinuous; Y, Young DIS; MA DIS, middle-aged DIS; (B) Y CON, Young Con; MA CON, middle-aged CON.

time [visit 1 and 2 average vs. visit 3]) repeated measures ANOVA was carried out to determine within group differences. If significant differences were detected, a Sidak post hoc test was used to determine where the differences were found with a priori significance set at $\alpha \leq 0.05$.

Results

Subjects

There were no significant differences in any subject characteristics before training, nor did any significant changes in weight or body composition occur with the training programs (Table 1). Each subject adhered to all 12 of the training sessions.

Performance Measures

Both groups exhibited a significant improvement in $\dot{V}O_2$max ($p < 0.001$) and heart rate$_{max}$ ($p \leq 0.05$) after exercise training (Table 2). However, there were no differences between the CON and DIS AE training groups. These data indicate that the training was successful and imposed enough stress to elicit physiological changes. Therefore, we are able to examine the effects of improved performance on hemodynamic variables and blood flow.

Hemodynamic Variables

Resting supine hemodynamic variables are presented in Table 2. A group × age interaction was observed, with middle-aged DIS subjects, there was a significant decrease in SBP ($p \leq 0.05$) comparedwith the younger group (Figure 1A). Additionally, the younger CON group displayed significant SBP decreases ($p \leq 0.05$) compared with the middle aged group (Figure 1B).

Pulse Wave Analysis and Velocity

Before training, there were no significant differences between groups seen in any variable for either pulse wave analysis (PWA) or pulse wave velocity (PWV) (Table 2). After training, augmentation index normalized for a 75 $b \cdot min^{-1}$ heart rate (AIx) significantly decreased in both groups. Divergent results were observed in the middle aged group compared with the younger, regardless of training mode ($p = 0.021$; Figure 2). Both central and peripheral PWV significantly decreased after training ($p < 0.001$). Central PWV (cPWV) showed a significant sex × time interaction ($p = 0.02$). Regardless of group or age, females displayed a significant decrease in cPWV compared with males (Figure 3).

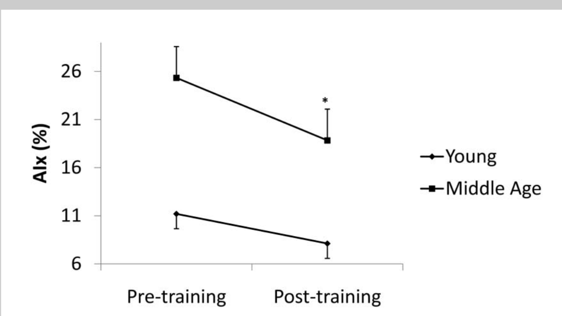

Figure 2. Age-related differences after training. Middle-aged decreased significantly compared with Y. *$p < 0.05$ mean ± *SEM*. Y, Young.

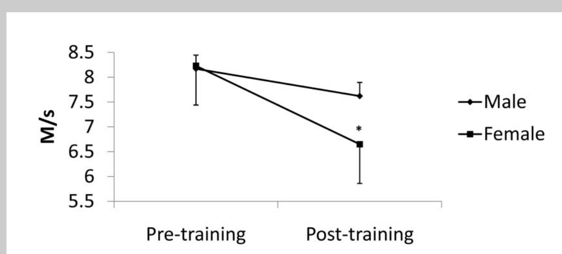

Figure 3. Sex-related changes after training. Females significantly decreased central PWV when compared to males. *$p < 0.05$ mean ± *SEM*. PWV, pulse wave velocity.

Forearm Blood Flow and Reactive Hyperemia

Average FBF and peak FBF both significantly increased after training in both groups ($p \leq 0.001$; $p = 0.001$, respectively; Table 2). Area under curve of FBF ($p < 0.0001$) and AUC peak FBF after RH ($p < 0.0001$) significantly increased pretraining to posttraining. There were no differences between training groups.

Discussion

The main finding in our study was that both moderate intensity protocols of CON and DIS AE are effective interventions which improve fitness, blood pressure, blood flow, and hemodynamics in healthy low-risk subjects. We found that both modes elicit a significant reduction in SBP and DBP, with divergent effects noted for age. The younger cohort benefitted more strongly from the CON protocol, whereas the middle aged group did so from the DIS training. Both groups also displayed significant improvements to AIx and central and peripheral PWV. Sex differences were observed after training in the cPWV measure, with females experiencing a larger decrease in velocity. Although both groups significantly improved AIx pretraining to posttraining, the middle aged group saw significant changes when compared with the younger. Finally, both groups experienced significant improvements to both average FBF and peak FBF after RH and AUC average FBF and AUC peak FBF after RH.

In the present study, both groups exhibited a similar improvement in fitness after exercise training. This mirrors other studies that have evaluated comparable intensities (20) and durations (10) of CON or DIS. In previous studies where total work was kept constant between CON and DIS groups, both were found to result in similar fitness improvements, whereas studies that did not account for work differences showed significant differences between exercise groups (20). The exact mechanism that confers these adaptations remains unclear. However, Daussin et al. (12) suggested that the CON and DIS training improves fitness through different pathways. Continuous training improved fitness peripherally in skeletal muscles through mitochondrial biogenesis, whereas DIS improved fitness through both peripheral (ΔDa-$\dot{V}O_2$) and central (ΔQmax) adaptations. A persistent issue this study addresses is the estimation of $\dot{V}O_2$max and HR_{max} (13,21) or symptom limited graded tests (24). Although most studies conducted using moderate intensity AE during either DIS or CON bouts agree that some measures of CV fitness improve after training, there is considerable disagreement on which mode is more effective. Three studies have reported differential findings when comparing CON vs. DIS training at these intensities. De Busk et al. (13) saw greater improvements in $\dot{V}O_2$max for the CON group when compared with DIS. Murphy et al. (21) reported greater increase in $\dot{V}O_2$max in the DIS group compared with CON. Finally, Quinn et al. (26) also noted an increased $\dot{V}O_2$max after DIS training with no change in the CON group. The estimation of $\dot{V}O_2$max and HR_{max} could account for the divergent findings regarding performance improvements. We had hypothesized that with like intensities and durations of training bouts, both AE modes would prove effective at improving fitness. Indeed, we have shown that both moderate intensity CON and DIS AE are effective methods to this end. And the lack of significant differences between males vs. females, and young vs. middle-aged $\dot{V}O_2$ and HR are in line with previous assertions of adaptations to exercise training when comparing different ages and sexes (29). To our best knowledge, this study is the first to describe maximal $\dot{V}O_2$ and HR measures after similar intensity and duration CON vs. DIS AE training in low-risk individuals.

We found that in as little as 4 weeks of AE training, SBP can be decreased. Blood pressure reduction has been identified as a primary goal of hypertension therapy (7). These findings are in agreement with previous studies of our lab (9) showing that clinically significant changes to resting BP can be achieved in as little as 4 weeks through moderate intensity AE. In further support of our findings are large-scale longitudinal studies reporting modest (1–3 mm Hg) to large (8–20 mm Hg) reductions in SBP after AE in healthy and hypertensive populations, respectively (15,37). The reductions in BP found in the present study are clinically relevant, as a significant reduction in SBP of 3 mm Hg for normotensives has been shown to reduce cardiac morbidity by greater than 5%, stroke by 8–14%, and all-cause mortality by 4% (36). Thus, we can suggest that moderate intensity and volume DIS AE is an effective prophylactic against cardiovascular disease (CVD) and may be used in lieu of CON AE to the same end in middle aged populations. The BP response to chronic moderate intensity CON exercise training has been well described and generally agreed to decrease resting SBP effectively in adult populations (31). In a recent review by Kessler et al. (18), both younger and middle aged cohorts were reported to respond well to intermittent AE training (high intensity >90% $\dot{V}O_2$max), showing in most cases that intermittent training is at least as effective as continuous in reducing SBP and DBP. However, in the previous work no studies reported the examination of lower intensity DIS training on these age groups, and many of the intermittent studies failed to control for total work performed. The only available studies examining the effects of accumulated activity at similar moderate intensity workloads on BP are following acute exposure (23–25); therefore, we believe that our study is the first to describe the direct comparison of these 2 differing training modes at these intensities. Our findings are in agreement with the available acute studies describing a more pronounced improvement to SBP in the DIS compared with CON in adults (25). However, it should be noted that there is paucity in the literature concerning the comparison of chronic training effects on both young vs. middle-aged persons as well as the comparison between males vs. females in the SBP response when exposed to moderate intensity AE.

The significant increases in peak and average vasodilatory capacity found after either CON or DIS AE support the results of long-term AE training studies that have shown enhanced vasodilatory capacity in exercising muscles. This increase in flow-mediated dilation (FMD)–that is, the resulting blood flow after reactive hyperemia–has been shown before in both normotensive and hypertensive populations (17) after undergoing 12 weeks of less intense (brisk walking) but more frequent (5–7 $d \cdot wk^{-1}$) AE. Beck et al. used an intermittent protocol with similar intensities (65–85% HR_{max}, no reported duration of interval or times per week trained) for 8 weeks in non-medicated prehypertensive young adults. They found a significant improvement to FBF after training. These changes were attributed, at least in part, to increase in the nitric oxide metabolites nitrate and nitrite and to prostaglandin bioavailablity as well as reductions in endothelin-1 (3).

Our study showed improvements to arterial stiffness that mirror those found in acute training studies observing the differences between intermittent and continuous exercise (32). To reduce the influence of estrogen on the vasculature, our female population was either postmenopausal (middle-aged group) or tested within 5 days of beginning menses (young group). In a recent review of arterial stiffness (38), age was identified as a main determinant in large elastic arteries, with significant increases in stiffness observed in males after the age of 55 and in females after menopause. Although there is a body of evidence indicating that males and females are likely to present with CVD at different ages (2), there has been little research comparing younger and middle aged groups' response to like type, intensity, and duration of AE.

Similar reductions in cPWV and SBP were seen in more recent studies examining elderly populations with slightly higher intensities of training (35). These findings are salient because there is a mounting case that, regardless of the training mode (walking, running, cycling), DIS AE provides improved CV adaptations in a more time-effective way and may be superior to traditional continuous AE in some cases (11).

Our study was not without limitations, the greatest of which was the small number of subjects; however, the significant findings support future work on a larger scale in this area. This limitation resulted in one of the greatest strengths of the study design. To reduce the population size needed for effect, we implemented a counter-balanced approach where each subject participated in a wait period before beginning AE to serve as his or her own control. With larger sample sizes, a separate control group may be implemented to assist in determining the stability of these measures. A better-defined subject population could improve the reliability of our findings. We were limited to using "low-risk" populations (1), which included some subjects that barely met the criteria and some that were well trained. A more informative population would be unmedicated prehypertensive to stage-1 hypertensive or even those with a family history of CVD. These populations would greatly assist in determination of the effectiveness of CON vs. DIS training modes in persons who may become candidates for pharmacological intervention or are at risk for an adverse cardiac event.

In conclusion, this study shows that both CON and DIS AE are able to effectively modify prognostic indicators of CVD. We showed that both CON and DIS AE training can decrease SBP and improve FBF and FMD after RH without concomitant weight loss. However, for younger subjects, CON AE produced a more pronounced decrease in SBP, whereas middle aged subjects received greater benefit from DIS. Likewise, we saw divergent results in measures of arterial stiffness, with middle-aged subjects receiving a greater reduction in AIx and women experiencing a larger decease in cPWV, both regardless of exercise group. This suggests that, as we age, significant clinical improvements can be made with either type of AE–specifically, the reduction of CVD risk factors such as arterial stiffness or elevated BP–but some populations may benefit more from one type than from another.

Practical Applications

Given the increasing prevalence of CVD, and the increased presentation of PHTN in younger cohorts, it is essential to study which exercise mode, intensity, and duration may provide the best intervention to mitigate the burden of disease. The results of this study suggest that both CON and DIS moderate intensity AE are effective at improving clinical indicators of CVD, however not all populations benefit to the same degree from each.

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