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Effects of aerobic and/or resistance training on body mass and fat mass in overweight or obese adults

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[1]*Division of Cardiology, Duke University Medical Center, Durham, North Carolina,* [2]*Duke Center for Living, Duke University Medical Center, Durham, North Carolina,* [3]*Division of Geriatric Medicine, Duke University Medical Center, Durham, North Carolina,* [4]*Geriatric Research, Education and Clinical Center, Durham Veterans Affairs Medical Center, Durham, North Carolina,* [5]*Department of Exercise and Sports Science and Human Performance Laboratory, East Carolina University, Greenville, North Carolina*

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Willis LH, Slentz CA, Bateman LA, Shields AT, Piner LW, Bales CW, Houmard JA, Kraus WE. Effects of aerobic and/or resistance training on body mass and fat mass in overweight or obese adults. *J Appl Physiol* 113: 1831–1837, 2012. First published September 27, 2012; doi:10.1152/japplphysiol.01370.2011.—Recent guidelines on exercise for weight loss and weight maintenance include resistance training as part of the exercise prescription. Yet few studies have compared the effects of similar amounts of aerobic and resistance training on body mass and fat mass in overweight adults. STRRIDE AT/RT, a randomized trial, compared aerobic training, resistance training, and a combination of the two to determine the optimal mode of exercise for obesity reduction. Participants were 119 sedentary, overweight or obese adults who were randomized to one of three 8-mo exercise protocols: *1)* RT: resistance training, *2)* AT: aerobic training, and *3)* AT/RT: aerobic and resistance training (combination of AT and RT). Primary outcomes included total body mass, fat mass, and lean body mass. The AT and AT/RT groups reduced total body mass and fat mass more than RT ($P < 0.05$), but they were not different from each other. RT and AT/RT increased lean body mass more than AT ($P < 0.05$). While requiring double the time commitment, a program of combined AT and RT did not result in significantly more fat mass or body mass reductions over AT alone. Balancing time commitments against health benefits, it appears that AT is the optimal mode of exercise for reducing fat mass and body mass, while a program including RT is needed for increasing lean mass in middle-aged, overweight/obese individuals.

aerobic training; body composition; exercise; obesity; resistance training

THE BENEFITS OF REGULAR EXERCISE are well documented (1), but the rationale underlying the exercise mode recommendations for specific health benefits remains unclear due in large part to the sparse scientific data supporting these recommendations. Given that approximately two-thirds of U.S. adults are overweight or obese, clinicians require clear exercise guidelines based upon sufficient evidence from which to prescribe the most effective exercise plan (18).

Although professional organizations have historically focused exercise guidelines on endurance or aerobic training (AT) for weight loss and maintenance (14), recent guidelines and position statements targeting body weight reduction and maintenance have suggested that resistance training (RT) may also be effective for reducing fat mass (11). In some cases, guidelines may lead to misperceptions among clinicians, exercise professionals, and laypersons about the strength of the evidence regarding the effectiveness of RT for inducing weight and fat mass loss (11, 20, 32), leading the reader to believe that RT has been conclusively shown to reduce fat mass. However, a close examination of the published literature reveals that randomized controlled trials are inconclusive on this point (7, 9, 19, 23, 24, 26).

Given the imperative of reducing obesity rates, exercise guidelines must be based upon unequivocal evidence of specific relations between exercise mode and changes in body mass and fat mass. Interestingly, despite the prevalence of obesity and the existing multiple position stands promoting exercise for the treatment of obesity, there are few randomized trials that have directly compared the effects of sustained AT, RT, or a combination of the two (AT/RT) on fat mass in overweight and obese adults. Most of the published studies addressing RT and fat mass changes have compared RT to an inactive control group and not to AT. Furthermore, existing studies have not directly studied comparable amounts of AT and RT. Thus it remains to be determined whether a significant amount of RT will decrease fat mass in overweight and obese adults, whether AT or RT is more effective at fat mass reduction when exposure (time) is held constant, and whether a combination of aerobic and resistance training (AT/RT) provides additive improvements in body composition. The Studies of a Targeted Risk Reduction Intervention through Defined Exercise-Aerobic and Resistance Training (STRRIDE-AT/RT) study was designed, in part, to address the aforementioned questions in a large randomized comparative effectiveness research trial of primarily middle-aged overweight and obese men and women with cardiometabolic health risk.

METHODS AND PROCEDURES

Study population. The protocol was reviewed and approved by the institutional review boards at Duke University Medical Center and East Carolina University (ECU). Subjects recruited for the STRRIDE-AT/RT study were selected from those ($n = 3{,}145$) that responded to newspaper, magazine, internet, and word of mouth advertisements and were screened by phone. Of these, 2,661 did not meet entrance criteria or elected not to participate, leaving 484 eligible subjects, of which 250 were excluded after consent due to secondary inclusion or exclusion criteria. Therefore 234 subjects were recruited into the overall study (Fig. 1). Of these, 75% were recruited at Duke University with the remaining 25% recruited at ECU.

Inclusion criteria were age 18 to 70 years, sedentary (exercising ≤1–2 times/wk), overweight or moderately obese (body mass index 25–35 kg/m^2), and with mild to moderate dyslipidemia (either LDL

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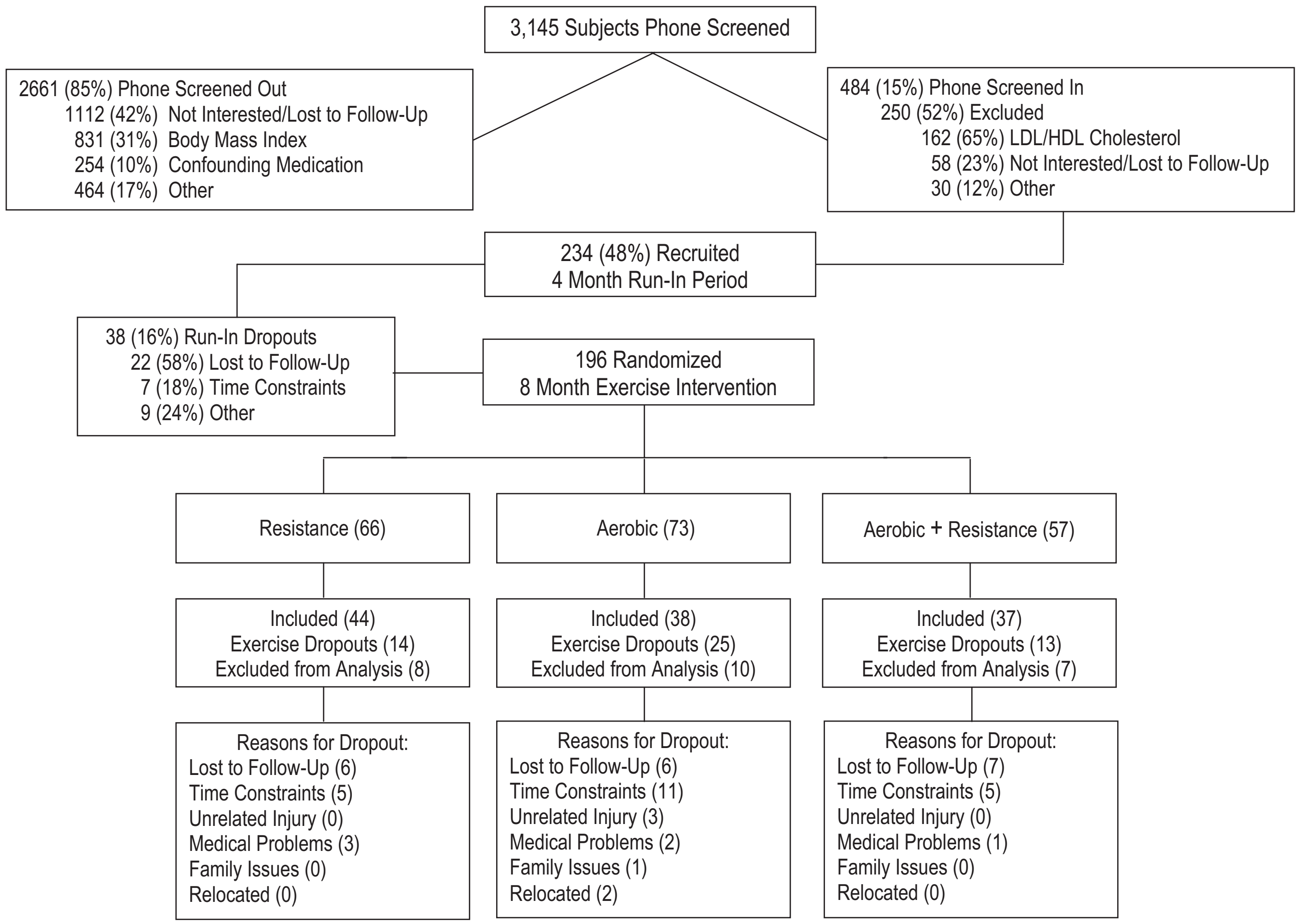

Fig. 1. Flowchart of screening and randomization inclusions and exclusions. An asterisk indicates excluded from analysis due to different testing modalities preintervention and postintervention for body composition measures.

cholesterol 130–190 mg/dl or HDL cholesterol ≤40 mg/dl for men or ≤45 mg/dl for women). Subjects were nonsmokers without a history of diabetes, hypertension, or coronary artery disease.

Subject randomization. After written informed consent was obtained and baseline tests were completed, all subjects were asked to maintain their current lifestyle for a 4-mo run-in period followed by preexercise testing, with subsequent randomization into one of three exercise training groups. We chose to have a control run-in period in hopes that less dedicated subjects would drop out prior to the initiation of the interventions. Importantly, this reduced dropouts that occurred after randomization and improved study validity. Indeed, our dropout rate after randomization decreased substantially for the current study compared with the first STRRIDE study (27). Ninety percent (211) of the subjects recruited completed the run-in period and were then randomized to an exercise group. Of those randomized, 155 subjects (74%) completed the study. A subset of this group (119; 77%) had consistent measurements of body composition using the same modality for both of the testing periods. Data from these subjects are included in the present analysis (Fig. 1).

Exercise training protocols. The exercise groups were as follows: *1)* resistance training (RT), (3 days/wk, 3 sets/day, 8–12 repetitions/set); *2)* aerobic training (AT), (calorically equivalent to ~12 miles/wk at 65–80% peak VO_2); *3)* aerobic training plus resistance training (AT/RT), (calorically equivalent to ~12 miles/wk at 65–80% peak VO_2 plus 3 days/wk, 3 sets/day, 8–12 repetitions/set).

A ramp period of 8 to 10 wk, designed to gradually increase the amount of aerobic exercise done over time, was prescribed to all subjects in the AT and AT/RT groups. Details of the prescribed and actual exercise training amounts by group are included in Table 1. Exercise modes included treadmill, elliptical trainers, and cycle ergometers for the aerobic exercises. All aerobic exercise sessions were verified by direct supervision and/or use of a heart rate monitor that provided recorded, downloadable data (Polar Electro, Inc; Woodbury, NY). Aerobic compliance percentages were calculated each week as a percentage, equal to the number of minutes completed within the prescribed heart rate range divided by the number of total minutes prescribed. All weekly compliance percentages are shown in Table 1.

For subjects randomized to resistance training, the ramp period began with one set during *weeks 1–2*, two sets during *weeks 3–4*, building up to the prescribed three set amount on *week 5*. The resistance training groups were prescribed three sessions per week, three sets each session of 8–12 repetitions, designed to target all major muscle groups. Weightlifted amounts were increased by 5 lbs each time the participant performed 12 repetitions with proper form on all three sets during two consecutive workout sessions. All resistance training sessions at Duke were verified by direct supervision and/or use of the FitLinxx Strength Training Partner, (FitLinxx; Norwalk, CT). At the ECU site, sessions were confirmed via visual observation by fitness staff. Throughout each workout, the "training partner" captured and stored information including the amount of weight lifted, verified by infrared laser, and the number of repetitions and sets completed within the preprogrammed speed and range of motion limits. All weekly compliance percentages are shown in Table 1.

Table 1. *Baseline demographics and exercise prescription*

Variables	Resistance Training (n = 44)	Aerobic Training (n = 38)	Aerobic + Resistance (n = 37)
Age	50.1 (11.6)	52.0 (8.9)	47.0 (10.3)
Body mass index, kg/m^2	30.5 (3.4)	30.6 (3.2)	30.5 (3.4)
Race			
Caucasian	37	33	31
African American	6	5	5
Other	1	0	1
Gender			
Female	26	21	21
Male	18	17	16
Food Intake			
Kcals per day	2,009 (569)	2,100 (478)	2,009 (570)
RESISTANCE exercise			
Intensity	Progressive		Progressive
Rx amount, sets/wk[a]	72		72
Rx time, min/wk	180		180
Adherence, %	83.6 (12.6)		81.0 (15.0)
Actual frequency, sessions/wk	2.53 (0.38)		2.46 (0.44)
Actual amount, sets/wk[b]	60.2 (9.1)		58.3 (10.8)
AEROBIC exercise			
Intensity, % peak VO_2		65–80	65–80
Rx amount, $kcal \cdot kg^{-1} \cdot wk^{-1}$[c]		14	14
Rx time, min/wk		133.5 (25.3)	133.6 (26.0)
Adherence, %		89.0 (10.2)	82.1 (18.3)
Actual frequency, sessions/wk		2.99 (0.52)	2.88 (0.63)
Actual time, min/wk[d]		117.6 (19.5)	109.3 (29.6)

Values are means (SD). There were no significant baseline differences between groups. [a]Rx amount (72 sets/wk) = 3 days/wk, three sets of 8–12 reps, on eight different machines. [b]Actual amount (sets/wk) = Rx amount × adherence. [c]Rx amount (14 $kcal \cdot kg^{-1} \cdot week^{-1}$) is approximately calorically equivalent to 12 miles of jogging per week. [d]Actual time (min/wk) = Rx time × adherence.

Anthropometrics and body composition. Height was measured to the nearest 0.25 cm and body mass determined in light clothing without shoes to the nearest 0.1 kg on a digital scale (Scale 5005; ScaleTronix Inc, Wheaton, IL). Waist circumference was taken at the minimal waist (smallest horizontal circumference between the umbilicus and xiphoid process). At Duke, body composition was determined using the BOD POD air displacement plethysmography method (Life Measurement, Concord, CA) on all subjects at all time points. At ECU, body composition was measured by dual energy X-ray absorptiometry machine (DEXA). As previously reported, measurements with BOD POD and DEXA are highly correlated (0.94) with one another (3). Furthermore, the focus of this analysis was on preintervention/postintervention change scores; thus any differences between the study sites due to the techniques used to assess body composition did not affect the data interpretation.

Nutrition. Calorie intake was assessed using a 3-day food record and a 24-h recall interview conducted at the beginning and end of the training period. Dietary intakes recorded from the 3-day records and 24-h recalls were analyzed for calorie and macronutrient content using Food Processor Nutrition Analysis Software (Version 7.1, 1996, ESHA Research, Salem, OR), which provides access to information on over 15,000 food items with data for 105 nutrient components. Confirmation of nonsignificant variability between the two measures permitted us to combine the two measures and calculate a mean energy intake over 4 discrete days at each time point.

Computed tomography. Noncontrast enhanced computed tomography (CT) scans were performed on a General Electric CT/I (GE Medical Systems, Milwaukee, WI). An experienced CT technologist who was blinded to the study randomization performed the CT imaging studies. With subjects in a supine position, a single, 10 mm axial image was taken at the midpoint of the left thigh (midway between the acetabulum and the patella) as determined from frontal scout radiographs. The CT images were analyzed using Slice-O-Matic imaging software (Tomovision, Montreal, QC, Canada) to determine thigh muscle area. An attenuation range of 0° to 100° Hounsfield units was implemented for thigh muscle.

Cardiopulmonary exercise test. Cardiopulmonary exercise tests (CPET) with a 12-lead ECG and expired gas analysis were performed on a treadmill using a TrueMax 2400 Metabolic Cart (ParvoMedics; Sandy, UT). The two highest, consecutive, 15-s readings from each test were averaged to determine absolute peak VO_2 (l/min).

Strength evaluation. The upper and lower body total amounts of weight lifted (pounds) from a single session during *week 5* were used as the baseline measure of overall strength. The same measurements from a single session at *week 32* were used as the end of training measure of overall strength. The difference in these two amounts constituted the overall strength gains expressed in pounds lifted/session.

Statistical methods. Data were analyzed using analysis of variance (ANOVA; Statview or SAS Software, SAS Institute, Cary, NC). When the ANOVA was impressionable ($P < 0.10$), a Fisher's PLSD post hoc analysis was performed to determine differences between groups (Fig. 2). The analysis intentionally was restricted to three pairwise comparisons (the AT, RT, and AT/RT exercise groups compared with each other). $P < 0.05$ was considered significant in post hoc testing. Paired, two-tailed t-tests were used to determine if the post vs. pre score for changes within each group differed.

RESULTS

Baseline demographics and exercise prescription data are presented for each group in Table 1. There were no significant between-group differences in any baseline measures. As presented in Table 1, adherence was slightly lower for each portion of the AT/RT group than for either AT or RT, but the total time accumulated for the AT/RT group remained almost double that of the other two groups. Figure 1 describes the flow of participants from recruitment to postintervention testing. Of the 234 subjects who entered the 4-mo run-in phase of the study, 196 (83.7%) returned and were randomized to one of three exercise groups. There was a 26.6% dropout rate from the

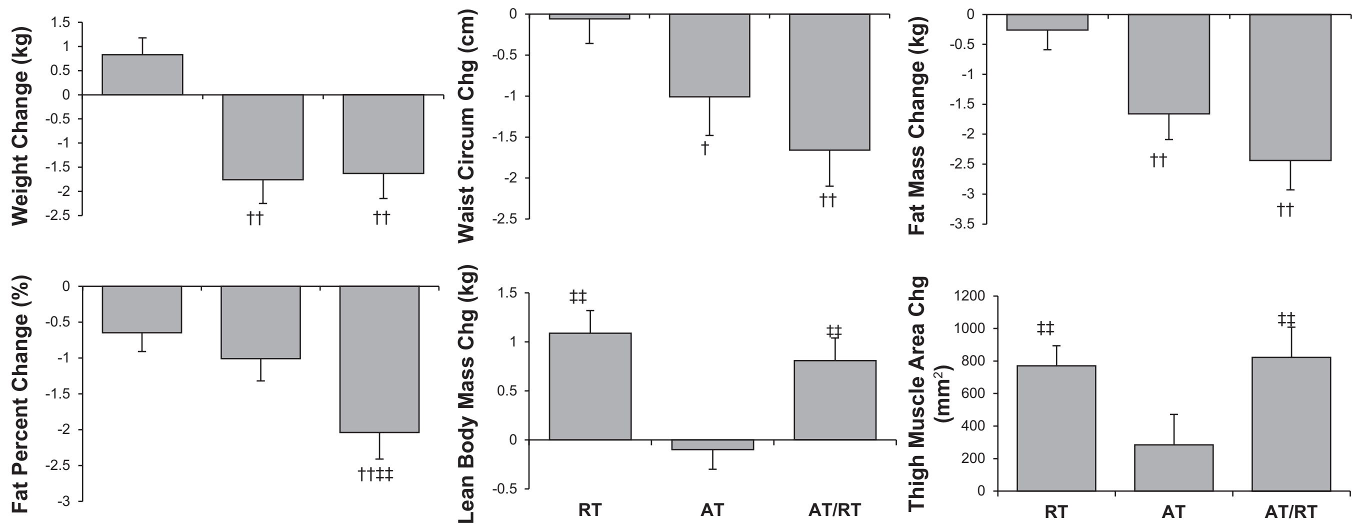

Fig. 2. The effect of different modes of exercise on change in measures of body mass and body composition. Error bars indicate SE. ††$P < 0.05$, †$P < 0.10$ Fisher's Post Hoc Test compared with resistance training. ‡‡$P < 0.05$ Fisher's Post Hoc Test compared with aerobic training.

exercise intervention across all groups, leaving 155 to complete the study intervention and testing. For the body composition analysis, 119 subjects had consistent assessment methodologies at all testing time points.

Measures of body composition. Baseline and change scores for the variables of interest are presented in Table 2. The increases in peak VO_2 in each exercise group demonstrated the effectiveness of the training stimulus, as did the results for strength in the groups that incorporated resistance training. Reported energy intake was not different between baseline and end of training in any of the exercise groups, nor was it changed in the group as whole (data not shown). Body mass significantly decreased in the AT and AT/RT but significantly increased in RT. Fat mass and waist circumference significantly decreased in the AT and AT/RT groups but were not altered in RT. Measures of lean body mass significantly increased in RT and AT/RT but not in AT.

Figure 2 depicts the effect of the exercise mode (AT or RT) on changes in body composition. The two modes of exercise consistently differed in their effects on body composition. Body weight and fat mass significantly decreased in both AT and AT/RT but not in RT, suggesting that aerobic exercise is more effective in changing these measures. However, the change in lean body mass in both RT and AT/RT was significantly greater than that in AT, a finding supported by similar observations for the measure of thigh muscle area. Having the benefit of both modes of exercise allowed AT/RT to decrease body fat percent significantly more than either AT or RT, due to decreased fat mass combined with increased lean body mass. Similarly, there was an apparent additive effect of the two modes of exercise on waist circumference, as AT/RT significantly decreased waist circumference more than AT or RT.

DISCUSSION

For some time we have been interested in how much exercise and what types (modes) are most beneficial for acquiring health effects, cognizant of the fact that not any one amount or type of exercise is likely to be best for every health benefit (29). Previous research has shown RT to improve glucose tolerance and glycosylated hemoglobin, as well as strength and lean body mass (25). However, the influence of RT on other metabolic variables is less clear. Of considerable interest to both the general public and the scientific community are the control of weight gain and the extent of weight loss and change in body composition induced by exercise training. The STRRIDE-AT/RT research study provided a unique opportunity to investigate the relative benefits of resistance training when compared with aerobic training and the

Table 2. *Baseline values and change scores*

	Resistance Training (n = 44)			Aerobic Training (n = 38)			Aerobic + Resistance Training (n = 37)		
Variable	Baseline	Change	P Value	Baseline	Change	P Value	Baseline	Change	P Value
Body weight, kg	88.7 (15.6)	0.83 (2.32)	0.022*	88.0 (11.1)	−1.76 (3.00)	0.001*	88.9 (11.5)	−1.63 (3.17)	0.004*
Peak VO_2, ml/kg/min	27.0 (6.24)	1.26 (2.38)	0.001*	27.3 (5.57)	3.43 (3.54)	<0.0001*	27.0 (5.78)	4.25 (2.97)	<0.0001*
Strength, kg/session	9094 (3373)	4306 (2630)	<0.0001*	N/A	N/A	N/A	8779 (2704)	3810 (2508)	<0.0001*
Food intake, kcal/day	2009 (569)	−81.8 (621)	0.435	2009 (570)	−66.4 (320)	0.203	2100 (478)	−133.8 (547)	0.1348
Fat mass, kg	34.3 (9.12)	−0.26 (2.16)	0.429	34.7 (7.89)	−1.66 (2.67)	0.001*	34.9 (8.92)	−2.44 (2.97)	<0.0001*
Lean body mass, kg	54.4 (13.3)	1.09 (1.54)	<0.0001*	53.3 (8.71)	−0.10 (1.22)	0.613	54.0 (9.59)	0.81 (1.38)	0.001*
Fat %	38.8 (8.69)	−0.65 (1.70)	0.015*	39.4 (7.17)	−1.01 (1.92)	0.003*	39.2 (8.12)	−2.04 (2.23)	<0.0001*
Thigh CT muscle area, mm^2	13431 (3215)	681.9 (594.1)	<0.0001*	13523 (2660)	43.4 (324.5)	0.477	13247 (2686)	587.4 (697.6)	<0.0001*
Waist circumference, cm^2	93.6 (9.06)	−0.06 (1.96)	0.848	96.1 (10.25)	−1.01 (2.91)	0.039*	97.3 (8.89)	−1.66 (2.65)	0.001*

Values are means (SD). There were no significant baseline differences between groups. Fat mass, lean body mass, and fat % are from either BOD POD or DEXA.

combination of the two on body composition measures, particularly total body mass and fat mass.

To our knowledge, the current report represents the largest randomized trial to directly compare changes in body composition induced by comparable amounts of time spent doing resistance and aerobic training, or both in combination, in nondiabetic, previously inactive overweight or obese adults. Although RT and AT are vastly different in terms of the nature of the training stimulus (i.e., intermittent vs. continuous contractions, time skeletal muscle is under load, metabolic pathways utilized, and others), the basis for comparison was that the prescriptions utilized were consistent with national recommendations for the general population. The main findings of the study were the following: *1)* A substantial amount of RT alone did not reduce body mass or fat mass; *2)* recommended amounts of AT were significantly better than RT for reducing measures of body fat and body mass; and *3)* the combination of aerobic and resistance training did not provide an additive effect for reducing fat mass or body mass compared with AT alone. Thus the training modes in combination neither acted in synergy nor interfered but rather seemed to act in a linear fashion when body composition measures were the outcome variables.

Resistance training and changes in total body mass and absolute fat mass. The RT exercise prescription used in this study represents the upper limit of the amount recommended by the American College of Sports Medicine in terms of both sessions per week and number of sets per session (31). RT induced significant gains in lean body mass and strength (Table 2). The lack of body mass loss observed with RT in this study supports the findings of others and is driven by an increase in lean body mass (6, 7, 9, 11, 21, 24, 26). However, there are conflicting reports in the literature on whether or not RT induces fat mass loss: some randomized controlled trials find that RT significantly reduces fat mass (24), while others either report a statistically insignificant trend (23, 26) or no change in fat mass (7, 9, 19). The present study supports the latter observation. However, it should be emphasized that RT significantly ($P < 0.05$) improved lean body mass as confirmed by both BOD POD and thigh muscle area measurements.

Recommendations from the American College of Sports Medicine (2009) provide a figure that proposes three potential mechanisms by which RT might lead to fat mass loss (11). Although the authors state that the literature examining the effect of RT on fat mass is inconclusive and that resistance training is not effective for weight loss, RT is still endorsed as an effective means for obesity treatment. Similarly, other consensus documents and study reports include tables showing that RT results in decreases in fat percentage, with the suggestion that this decrease in fat percent indicates a decrease in fat mass (4, 12, 17, 20, 32). The problem with reporting changes in fat percent, instead of absolute fat mass, is demonstrated by the RT group in the present study, for whom fat percent did significantly decrease without any change in absolute fat mass. In other words, the changes in percent body fat were driven solely by the increase in lean body mass induced with RT. The present study failed to observe significant total body or fat mass loss even with a very substantial resistance training program of 8 mo duration.

Perhaps the most commonly cited reason for the reduction of fat mass and body weight by RT is that resting metabolic rate (RMR) theoretically increases as lean body mass increases (10, 16, 20, 22), resulting in a steady state increase in total energy expenditure and a corresponding negative shift in energy balance. Although we did not directly measure RMR in the present study, we observed that RT increased lean body mass without a significant change in fat mass or body weight, irrespective of any change in RMR that might have occurred. Given these observations, along with those from other studies (7, 9, 19), it may be time to seriously reconsider the conventional wisdom that RT alone can induce changes in body mass or fat mass due to an increase in metabolism in overweight or obese sedentary adults.

Aerobic vs. resistance training and body composition changes. It is important for the clinician to understand whether aerobic or resistance training is superior in inducing changes in overall body composition. Comparisons between AT and RT groups in the current study suggest that AT decreases both body weight and fat mass significantly more than does RT. While the two modes of exercise produced statistically similar changes in body fat percentage, these changes were driven by different mechanisms, where RT increased lean body mass and AT decreased fat mass. These data are supported by other findings from this trial that indicate AT significantly reduced visceral adipose tissue more than RT and trended toward the same result in liver fat change (28). Additionally, the present study suggests that AT trended toward significantly improving metabolic syndrome score better than RT (5). Furthermore, a recent meta-analysis of aerobic vs. resistance training effects on visceral fat concludes that there is a trend ($P = 0.08$) toward a greater reduction in visceral fat with AT when compared with RT (13). These data taken together and combined with the knowledge that the RT program in STRRIDE AT/RT was equivalent to the top end of those suggested in recent exercise guidelines (1) provides compelling evidence that AT is the optimal mode of exercise for improving body fat amount.

We found few large randomized controlled trials that examined the effects of both AT and RT on overweight or obese adults. Sigal et al. examined AT, RT, and a combination of the two in a diabetic population (26). They observed a significant reduction in both body mass and fat mass with AT and a trend toward decreased fat mass with RT, but RT produced no change in body mass compared with inactive controls. While intuitively these results suggest that AT is more effective than RT, no direct comparison was made between AT and RT in the statistical analysis, and therefore no definitive conclusions could be drawn between the two modes of exercise from this study. In another study, Davidson et al. examined AT, RT, and a combination of the two (9), where the RT group did only one set of training, three times per week, for a total of 60 min of training per week, while the AT group exercised for 150 min per week. The time disparity between the groups in the study by Davidson et al. limits the comparison of the effectiveness of the two modes of exercise on body composition. Time spent exercising does not equate to energy expenditure of the exercise performed, as the RT time includes the times spent recovering between sets and moving between the various machines. However, comparisons based on total time spent exercising do help clarify which mode of exercise is most efficient in affecting the variables of interest. In STRRIDE AT/RT, the AT group averaged 133 min/wk of training compared with ~180 min/wk for RT, thereby avoiding the confounding that could occur when the times spent in exercise per week are vastly different between the two groups. Thus based on the STRRIDE AT/RT data in which similar exercise times were prescribed, AT was the more efficient method of exercise for favorable changes in body fat.

Combined aerobic and resistance training. We also examined whether the addition of RT to an AT program provided any additional benefits for reduction in fat mass. A 2000 American Heart Association Science Advisory (20) states that RT complements AT for weight control. And a recent study from Church et al. found the combination of AT and RT improved fat mass significantly more than AT alone in type II diabetics (8). However, the observations of STRRIDE AT/RT suggest that adding RT did not significantly improve upon the results of the AT group in inducing weight control in an nondiabetic, inactive, overweight, and middle-aged cohort. Perhaps the demographic differences between the two studies offer an explanation for the different conclusions. The findings of STRRIDE AT/RT are supported in the previously cited report by Davidson *et al*. (9) that examined which method of exercise is most effective when time is held constant in a nondiabetic population. Both the AT and AT/RT groups in that study exercised for 150 min per week and were significantly better at body and fat mass reduction than the RT group but were not significantly different from each other. While they observed combined AT/RT exercise to be optimal for improving functional limitations, this was not true for body fat mass. The present study strengthens this observation, as similar body weight and fat mass losses were observed in the AT and AT/RT groups even though the exercise duration in the combined group was approximately twice that of the AT group.

Waist circumference. There is increasing evidence that central obesity is more strongly correlated with cardiovascular disease than measures of general obesity, such as BMI and body mass (2, 15, 30). It is important therefore to note that the combined AT/RT exercise group decreased minimal waist circumference significantly more than did RT. Perhaps the significant increase in exercise duration for the combined group explains this finding. However, the AT group trended ($P = 0.09$) toward significantly decreased waist circumference by a greater increment than did RT and as previously stated, the time commitment was similar between these groups. It is possible that a larger sample size would detect that AT was more effective than RT for reducing this measure and further research is needed.

Strengths and limitations. Important strengths of this study include: *1)* the randomized design; *2)* the inclusion of three training programs in the same study; *3)* the direct verification of exercise for nearly all training sessions; *4)* inclusion of a substantial RT program that reduced the likelihood that negative findings were due to the failure to provide an adequate RT stimulus in this group; *5)* the additive nature of the combination program, permitting the assessment of additive or interacting effects of AT and RT in the combination group; and *6)* a large number of subjects, providing excellent statistical power to detect exercise effect differences between intervention groups. The power value for the variables included in this manuscript ranged from 0.95 to 1.0. One limitation of this study is that this was not an intent-to-treat analysis. Additionally, the participants in this study were motivated men and women who volunteered to exercise in a semisupervised setting, perhaps limiting generalizability of the findings to a nonsupervised group in the general population.

Conclusion. The data support the following conclusions. Although it was more effective for lean body mass gains, RT did not significantly reduce either fat mass or total body mass. AT was more effective than RT for the reduction of fat and body mass in previously sedentary, nondiabetic, overweight or obese adults. While requiring double the time commitment, a program of combined AT and RT did not result in a greater loss of fat mass or body mass over AT. If increasing muscle mass and strength is the goal, a program including RT is required. However, balancing time commitments against health benefits accrued, it appears that AT alone is the optimal mode of exercise for reducing fat mass and total body mass.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: L.H.W., C.A.S., L.A.B., A.T.S., and L.W.P. performed experiments; L.H.W. and C.A.S. analyzed data; L.H.W., C.A.S., and W.E.K. interpreted results of experiments; L.H.W. prepared figures; L.H.W. drafted manuscript; L.H.W., C.A.S., L.A.B., A.T.S., L.W.P., C.W.B., J.A.H., and W.E.K. edited and revised manuscript; L.H.W., C.A.S., J.A.H., and W.E.K. approved final version of manuscript; C.A.S., C.W.B., J.A.H., and W.E.K. conception and design of research.

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