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An evaluation of endurance and combined endurance and resistance training on fitness and C-reactive protein

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AN EVALUATION OF ENDURANCE AND COMBINED ENDURANCE AND RESISTANCE TRAINING ON FITNESS AND C-REACTIVE PROTEIN

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ABSTRACT

PURPOSE: This study was designed to determine whether endurance or endurance + resistance training would influence circulating C-reactive protein (CRP) levels and if these changes are related to alterations in aerobic fitness and/or body composition. METHODS: Fifty eight healthy young adults aged 18-24 yrs (78% female) were assigned to one of three groups: 1) endurance training (E) (n=18), 2) endurance + resistance training (ER) (n=11), or 3) active control (AC) (n=29). The E group completed 15 weeks of endurance training for either a half marathon (n=6) or full marathon (n=12). The ER group performed 15 weeks of periodized resistance training in addition to the half marathon (n=3) or full marathon (n=8) training. The AC group continued the same exercise routine that they had used prior to becoming a study participant. Pre and post measures included: a 1.5 mile run, 8 rep max (8 RMs; ER group only) on the bench and leg presses, height, weight, waist and hip circumference, DXA, and plasma CRP (ELISA). RESULTS: At baseline, no significant differences were observed between groups. In the E group only, estimated VO_2 max significantly increased 12.45% from 38.9 ± 3.8 ml/min/kg to 43.8 ± 7.5 ml/min/kg (mean ± SD) ($P < 0.05$) and total percent body fat decreased significantly 1.7% from 29.4% ± 8.3 to 27.7 ± 8.8 (mean ± SD) ($P < 0.05$). In the ER group only, plasma CRP concentrations decreased, but not significantly from 1.59 ± 1.2 mg/L to 0.99 ± 0.5 mg/L (mean ± SD) ($P = 0.16$). All other measures for the ER group did not change significantly. In addition, while the E and AC groups remained in the average risk category for CRP levels (1-3 mg/L) at the post intervention time point, the ER group entered the low risk category (< 1 mg/L) with an average CRP concentration of 0.99 mg/L. CONCLUSIONS: Combined endurance and resistance training may be an effective modality for reducing plasma CRP in young

adults. However, improvements in aerobic capacity and total percent body fat do not appear to affect changes in CRP. FUNDING: Louisiana State University

CHAPTER 1 INTRODUCTION

Cardiovascular disease (CVD) is the primary cause of death among developed Western countries and is associated with more deaths of Americans than any other known disease accounting for more than 40% of deaths annually (1). Risk evaluation and CVD reduction efforts have advanced with the progression of screening and treatment options after several risk factors were identified through studies such as the Framingham Heart Study and the Seven Countries Study (2; 3). Accordingly, the present recommended measures for decreasing CVD risk include eliminating smoking, following proper nutrition, engaging in regular physical activity, the alleviation of stress, and the management of blood pressure, cholesterol, and weight (4).

Despite efforts to expand the public awareness, CVD remains the current major cause of death for men and women worldwide. Even with the decline of common CVD risk factors such as smoking, high blood pressure, and cholesterol, cardiovascular events still occur in individuals who do not exhibit traditional risk factors (4). Therefore, current research has focused on other risk factors that have shown a strong ability to predict CVD, namely C-reactive protein (CRP), lipoprotein, fibrinogen, and homocysteine (4).

While low density lipoprotein (LDL) is the primary cholesterol-carrying lipoprotein and a causal factor in the development of cardiovascular disorders, more recent evidence is suggesting that serum levels of CRP may be a more powerful predictor of CVD risk (5). C-reactive protein is an acute phase protein produced primarily by the liver (6; 7). Levels of CRP rise during inflammatory stimuli responses due to increases in levels of interleukin-6 (IL-6) (7; 8). Even though CRP has been a crucial topic in research over the past decade, research has produced inconsistent answers about the best methods to lower CRP levels.

CHAPTER 2 LITERATURE REVIEW

CROSS-SECTIONAL STUDIES EVALUTING FITNESS LEVEL AND CRP

Several cross-sectional, epidemiological studies have demonstrated an inverse relationship between CRP levels and physical activity (5). Furthermore, many of these studies show that the relationship between CRP and physical activity is graded, such that increases in physical activity and fitness levels are inversely associated with decreased CRP levels (5). The link between changes in CRP and physical activity in exercising populations is also relevant in recreational or leisure-time activities (9). In a survey involving over 15,000 participants, it was determined that lower levels of CRP (<3.0mg/L) were found in individuals who participated in vigorous intensity (metabolic equivalent (MET) level of 6+ for individuals over the age of 60 and 7+ for individuals under the age of 60) leisure exercise 3 times per week or 5 times per week at a moderate intensity (no more than two sessions of exercise at a vigorous MET level) (9). Additional support is given when considering that Tomaszewski et al. found that when CRP levels in lean ultra-marathon runners (40-100km of running per week for > 2 years) were compared to lean sedentary controls, lean runners had the lowest CRP level (10). This study showed that when non-lean runners and the non-lean controls were compared, not only did the non-lean runners have lower CRP values, they also had lower values when compared to the lean controls. This supports the theory that exercise may be an effective means of reducing CRP levels. Thus, the epidemiological evidence to date indicates that CRP is a predictor of CVD and can be influenced by physical activity participation in those who do not already maintain a high level of fitness.

Considering the correlations found in cross-sectional research between increased physical activity and decreased circulating levels of CRP, exercise intervention studies are now focusing on

the changes in CRP levels associated with chronic exercise. Currently, the results of these intervention studies vary.

AEROBIC EXERCISE TRAINING AND CRP

There is no general consensus among researchers on the effects of aerobic exercise interventions on changes in CRP. Past research has confirmed that aerobic exercise leads to an increase in maximal oxygen uptake and anaerobic threshold, indicative of a fitness gain (11). A cross-sectional investigation by Church et al. reported a significant inverse relationship between cardiorespiratory fitness level and circulating CRP in 722 men (5). This finding was independent of body composition and body fat distribution. Conversely, other studies have shown that regardless of whether or not participants significantly increased their fitness level after an aerobic exercise intervention, there was no significant change in circulating CRP levels when compared to control group participants (12). A 2004 study by Okita et al. found that improvements in fitness through a two month aerobic intervention designed for weight loss were related to decreases in CRP levels, but were not significantly correlated (13). Furthermore, an intervention study performed by Marcell et al. revealed that 4 months of regular aerobic exercise resulted in no significant change in circulating levels of CRP despite improved fitness levels (14). Similarly, a 12 month study by Campbell et al. using moderate aerobic exercise showed significant fitness improvements for both males and females through VO_2 max gains of 11% and 10.5%, respectively (15). However, no significant effects were noted for CRP. In summary, the majority of aerobic exercise intervention studies show no change in CRP levels. This finding is becoming more consistent as researchers are able to recruit more subjects into longer, supervised intervention studies.

RESISTANCE TRAINING AND CRP

To date, there has been little research to establish the influence of resistance training alone on circulating CRP levels. Emerging data provides initial support for the capacity of resistance training to reduce serum CRP in diseased populations (16; 17). For example, Olson et al. found decreases in CRP and other inflammatory biomarkers with moderate level resistance training in overweight adult women after a one year intervention (16). The resistance training program used in this study was progressive and consisted of at least two training sessions per week targeting all major muscle groups. Another study performed by Stewart et al. found a 58% reduction in serum CRP levels when both younger and older inactive groups were joined after a 12-week combined aerobic and strength training intervention (17). The two active groups included within this study did not have significant changes in CRP suggesting that active individuals already maintain a healthy level of serum CRP. Since there have been many studies finding no significant changes in CRP with aerobic interventions, perhaps resistance training may be the key modality essential for altering CRP.

Conversely, a 10-week study by Levinger et al. saw no significant changes in CRP with progressive resistance training for either of the two groups, one with high levels of metabolic risk factors and one with low levels of metabolic risk factors (18). Clearly, the results are inconsistent among the few studies that have examined serum CRP levels in relation to resistance training programs. Given that all but one of these studies involved only a few subjects with short intervention periods, future work may yield more convincing results.

THE ROLE OF EXERCISE INTENSITY ON CHANGES IN CRP

Exercise intensity may potentially influence the extent of CRP change over the course of an exercise program. Current research supports a role for high intensity exercise in decreasing CRP in aerobic exercise interventions (12; 13). However, some studies also imply that there is an upper limit for intensity in relation to producing a favorable change in CRP. In the 2 month study by Okita et al. (previously mentioned), the authors suggested that there may be an optimal training pace in which weight loss and CRP reduction can simultaneously occur (13). This idea was proposed when the study group that had the greatest weight loss also had the highest pace of weight loss, and while triglycerides and insulin resistance greatly improved, CRP levels did not change. The training plan for all participants involved a supervised 80 minute aerobic dance workout with an additional 30-60 minute bicycle or treadmill workout supervised two days each week. Participants were also expected to perform an unsupervised home-based workout one or more days each week. Since the supervised workouts were completed within the range of 60-80% of peak heart rate and the home-based workouts were subject to the participants' motivation, exercise intensity varied across the 200 women making the identification of a target intensity of exercise difficult.

It is also important to note that the majority of aerobic training programs, which study exercise and CRP, have been based on moderate or moderately vigorous intensity training. For example, the participants in a study by Vieira et al. worked at a level that ranged between 60-70% VO_2 peak (19). Despite the significant improvements in VO2 peak (7% increase) and CRP level (13.2% decrease) in the aerobic training group, there was no significant correlation found between the two. Furthermore, it is important to note that studies by both Campbell et al. and Wong et al. used work intensities between 60-85% of maximal heart rate, which improved fitness but failed to

alter CRP (15; 20). Perhaps more vigorous, supervised training regimens involving both aerobic and strength training may provide conclusive results about an optimal intervention aimed at altering CRP.

CRP AND BODY COMPOSITION

There is some debate as to whether changes in CRP are more attributable to changes in fitness or to changes in body composition. Body mass index (BMI), weight, waist circumference, and body fat percentage have previously been found to correlate with changes in CRP levels. In a multivariate analysis by Okita et al., BMI, total cholesterol, liver function, and diastolic blood pressure were independently linked with levels of CRP (13). However, many researchers have suggested that limitations arise when using BMI to account for true body composition. More evidence has been offered by Hammett et al. who found that while a trend existed between baseline levels of CRP and fitness, CRP was highly correlated with both BMI and adiposity (21). Despite this correlation, the 6-month, progressive exercise intervention, which consisted of three supervised and one unsupervised session each week, did not alter CRP levels. By the fourth month of training, participants were working at 80% of their estimated VO_2 max for 45 minutes. Final results showed a significant 18% positive change in fitness yet no change in weight, body fat percentage, glucose level, LDL cholesterol, or CRP (21).

On the other hand, in another study, one year of resistance training in overweight but otherwise healthy women resulted in a significant reduction in CRP and a 5.2% improvement in lean mass and a 4.4% decrease in fat mass (16). Furthermore, in a recent study, Vieira et al. found that 10 months of aerobic exercise compared to light stretching significantly lowered CRP which was found to correlate with reductions in total fat mass and trunk fat mass (19). Specifically, the

aerobic exercise group experienced changes in body composition with a 1.5% reduction in total body fat and a 2.5% decrease in trunk fat coupled with a 13.2% decrease in plasma CRP (19). Similarly, Kim et al. found that while all the measures of body fat were significantly correlated with CRP, visceral fat was the most significant indicator for CRP in both the exercising group and the non-exercising group (22). After considering these studies, perhaps there is a stronger link between serum CRP levels and visceral adipose tissue rather than total adiposity.

To the contrary, another previously mentioned study by Marcell et al. stated that while there was a clear correlation between CRP levels and percent body fat at baseline, no significant changes in CRP were found despite a significant 4% reduction in body fat in one of the three exercising groups (14). Additionally, while the combined aerobic and resistance training intervention study by Stewart et al. showed a positive relationship between body mass and CRP levels, the 58% CRP reduction occurred without any significant intervention-related changes in body mass or fat percent (17). It is important to note that this study used bioelectrical impedance to determine body composition rather than more precise methods such as dual energy X-ray absorptiometry (DXA) or hydrostatic weighing.

Based on the majority of current CRP research, it has been observed that a strong relationship exists between CRP and adiposity. This indicates that changes in CRP after an exercise intervention may be due to reductions in body fat, independent from total weight loss or gains in fitness. On the other hand, some researchers have also determined that CRP levels decrease after exercise despite the amount of weight loss or changes in adiposity (13). Such studies leave room for even more research looking to find other mechanisms by which CRP levels are related.

CONCLUSION AND SPECIFIC AIM

The potential for chronic exercise to induce changes in CRP has received more attention in the recent literature; however, researchers have failed to achieve a consensus on the topic. Since CRP has been identified as a predictor of CVD, it is essential that the scientific community explore natural methods of lowering this risk factor. It is clear that there may be some changes in CRP that are associated with exercise, but whether those alterations are due to changes in fitness, body composition, or some undiscovered mechanism are still being debated. In addition, little data exists on the potential effects of anaerobic and resistance training on circulating levels of CRP. This type of training could potentially be a missing link in previous studies and may prove to be a more viable therapy for CVD.

The purpose of this study is to determine whether endurance or endurance + resistance training could influence circulating CRP levels. This study will concentrate on two specific aims. First, this study will investigate whether endurance or endurance + resistance training will alter CRP levels. Secondly, this study will explore whether changes in CRP are more strongly related to alterations in body composition or fitness level.

CHAPTER 3 METHODS

PARTICIPANTS

Participants included 58 young adults enrolled at Louisiana State University (LSU). The subjects were both males and females aged 18-24 yrs. All of the participants were healthy, not pregnant, and able to complete a vigorous exercise training plan. Participants involved in the training intervention submitted a physician's clearance form in order to be accepted into the study.

All subjects were provided with an informed consent as well as a medical history form prior to beginning any training. Upon acceptance, each participant was assigned a random code. All information regarding the participant thereafter was viewed by code to assure confidentiality and privacy rights. This project was approved by the Louisiana State University Institutional Review Board.

STUDY DESIGN

All male and female 18-24 year old participants were assigned to one of three groups: 1) an endurance training (E) group, 2) a combined endurance + resistance training (ER) group, or 3) an active control (AC) group. The E and ER groups completed a marathon or half marathon training regimen. The ER group performed a 15-week periodized strength training regimen in addition to an altered marathon or half marathon training plan to account for the increase in workload. The AC group continued the same exercise plan that they had used prior to becoming a study participant and was not supervised.

Within the first two weeks of training, all pre-intervention measurements (1.5 mile run, 8 repetition maximum (RMs; ER group only), height, weight, waist and hip circumferences, DXA, 20mL blood sample) were completed on participants from all three groups. A complete study outline can be viewed in Figure 1.

PRE	Training Intervention	POST
1 day diet control		1 day diet control
Blood draws (20 mL)	← E (15 weeks) →	Blood draws (20 mL)
DXA		DXA
WHR	← ER (15 weeks) →	WHR
BMI		BMI
1.5 mile run	← AC →	1.5 mile run
8RM bench press (ER group)		8RM bench press (ER group)
8RM leg press (ER group)		8RM leg press (ER group)

Figure 1. Study outline.

During the 15-week intervention period, participants in the E and ER groups followed the designated training regimens consisting of endurance only (Table 1) for the E group and combined endurance + resistance (Table 2) for the ER group. These plans included several runs each week with a long run and cross-training on the weekend days. The duration of the aerobic workouts varied depending upon each individual's running pace. The endurance only workout for the E group was periodized and progressive in design. The resistance exercises performed by the ER training group were designed for runners and created by both the researcher and a certified strength and conditioning specialist (Table 3). All weekend long runs were supervised for both the E and ER groups. Training was documented and monitored for each participant to ensure adherence and progress. All resistance training (RT) was conducted with researcher supervision in the LSU stadium weight training room. Subjects completed two RT sessions separated by at least 24 hours each week at the LSU stadium weight training room and, with assistance from supervisors, they lifted to volitional fatigue during each exercise.

Table 1. Endurance training plan for the E group.

Marathon Training Plan (Distances in Miles) – E group								
Week	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**	**Sat**	**Sun**	**Total (miles/wk)**
1	Rest	3	3	3	Rest	6	Cross	15
2	Rest	3	4	3	Rest	7	Cross	17
3	Rest	3	4	3	Rest	8	Cross	18
4	Rest	3	4	3	Rest	7	Cross	17
5	Rest	3	5	3	Rest	10	Cross	21
6	Rest	3	6	3	Rest	12	Cross	24
7	Rest	3	5	4	Rest	11	Cross	23
8	Rest	4	7	4	Rest	14	Cross	29
9	Rest	4	8	5	Rest	16	Cross	33
10	Rest	4	9	5	Rest	18	Cross	36
11	Rest	5	9	5	Rest	20-22	Cross	39-41
12	Rest	5	10	5	Rest	20	Cross	40
13	Rest	5	10	5	Rest	12	Cross	32
14	Rest	5	6	5	Rest	8	Cross	24
15	Rest	3	4	2	Rest	RACE		
Half Marathon Training Plan (Distances in Miles) – E group								
Week	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**	**Sat**	**Sun**	**Total (miles/wk)**
1	Rest	1.5	1.5	1.5	Rest	3	Cross	7.5
2	Rest	1.5	2	1.5	Rest	3.5	Cross	8.5
3	Rest	1.5	2	1.5	Rest	4	Cross	9
4	Rest	1.5	2	1.5	Rest	3.5	Cross	8.5
5	Rest	1.5	2.5	1.5	Rest	5	Cross	10.5
6	Rest	1.5	3	1.5	Rest	6	Cross	12
7	Rest	1.5	2.5	2	Rest	5.5	Cross	11.5
8	Rest	2	3.5	2	Rest	7	Cross	14.5
9	Rest	2	4	2.5	Rest	8	Cross	16.5
10	Rest	2	4.5	2.5	Rest	9	Cross	18
11	Rest	2.5	4.5	2.5	Rest	10	Cross	19.5
12	Rest	2.5	5	2.5	Rest	12	Cross	22
13	Rest	2.5	5	2.5	Rest	11	Cross	21
14	Rest	2.5	3	2.5	Rest	4	Cross	12
15	Rest	3	4	2	Rest	RACE		

Rest, running or other intense aerobic exercise should not be performed. *Cross*, cross-training (swimming, cycling, etc.) should be performed for aerobic exercise rather than running.

Table 2. Endurance training plan for the ER group.

Marathon Training Plan (Distances in Miles) – ER group								
Week	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**	**Sat**	**Sun**	**Total (miles/wk)**
1	Rest	RT	3	RT + 3	Rest	6	Cross	12
2	Rest	RT	4	RT + 3	Rest	7	Cross	14
3	Rest	RT	4	RT + 3	Rest	8	Cross	15
4	Rest	RT	4	RT + 3	Rest	7	Cross	14
5	Rest	RT	5	RT + 3	Rest	10	Cross	18
6	Rest	RT	6	RT + 3	Rest	12	Cross	21
7	Rest	RT	5	RT + 4	Rest	11	Cross	20
8	Rest	RT	7	RT + 4	Rest	14	Cross	25
9	Rest	RT	8	RT + 5	Rest	16	Cross	29
10	Rest	RT	9	RT + 5	Rest	18	Cross	32
11	Rest	RT	9	RT + 5	Rest	20-22	Cross	34-36
12	Rest	RT	10	RT + 5	Rest	20	Cross	35
13	Rest	RT	10	RT + 5	Rest	12	Cross	27
14	Rest	RT	5	RT + 5	Rest	8	Cross	18
15	Rest	RT	4	RT + 2	Rest	RACE		13
Half Marathon Training Plan (Distances in Miles) - ER Group								
Week	**Mon**	**Tues**	**Wed**	**Thur**	**Fri**	**Sat**	**Sun**	**Total (miles/wk)**
1	Rest	RT	1.5	RT + 1.5	Rest	3	Cross	6
2	Rest	RT	2	RT + 1.5	Rest	3.5	Cross	7
3	Rest	RT	2	RT + 1.5	Rest	4	Cross	7.5
4	Rest	RT	2	RT + 1.5	Rest	3.5	Cross	7
5	Rest	RT	2.5	RT + 1.5	Rest	5	Cross	9
6	Rest	RT	3	RT + 1.5	Rest	6	Cross	10.5
7	Rest	RT	2.5	RT + 2	Rest	5.5	Cross	10
8	Rest	RT	3.5	RT + 2	Rest	7	Cross	12.5
9	Rest	RT	4	RT + 2.5	Rest	8	Cross	14.5
10	Rest	RT	4.5	RT + 2.5	Rest	9	Cross	16
11	Rest	RT	4.5	RT + 2.5	Rest	10	Cross	12.5
12	Rest	RT	5	RT + 2.5	Rest	12	Cross	19.5
13	Rest	RT	5	RT + 2.5	Rest	11	Cross	18.5
14	Rest	RT	3	RT + 2.5	Rest	4	Cross	9.5
15	Rest	RT	4	RT + 2	Rest	RACE		10

Rest, running or other intense aerobic exercise should not be performed. *Cross*, cross-training (swimming, cycling, etc.) should be performed for aerobic exercise rather than running.

Table 3. Resistance exercises from the three rotating workout plans for the ER group.

Workout A	**Workout B**	**Workout C**
Squat (barbell)	Leg extension	Dumbbell step ups
Seated Hamstring Curls	Romanian Dead Lift	Walking dumbbell lunges
Calf press	Dumbbell single leg calf raise	Dumbbell single leg calf raise
Dumbbell Abdominal Crunches	Abdominal rollouts	Leg raises
Cable twists	Woodchops	Tick Tocks
Dumbbell Side Bends	Oblique dips	Flat bench side crunches
Hyperextensions	Reverse hypers	Dumbbell Get-ups
Barbell Bench Press	Dumbbell pec flys	Incline dumbbell press
One-arm dumbbell upright rows	Dumbbell shrugs	Upright row
Seated Dumbbell Deltoid Presses	Dumbbell front deltoid raise	Dumbbell lateral raises
Wide Grip Pulldowns	Straight arm pulldown	V bar pulldown
Seated Cable Rows	1 arm dumbbell row	Reverse grip barbell row

This plan included three separate workouts (workout A, B, and C) in which lower body, core, and upper body were worked to volitional fatigue during each exercise. A preparatory phase (3 weeks), training phase (7 weeks), peak phase (1 week), and taper phase (3 weeks) were completed during the 15 weeks of resistance training. The RT plan was also periodized and progressive. Periodization is important in resistance training because it can facilitate larger gains in strength than other nonperiodized programs (23). The duration of the RT sessions varied depending upon each individual's workout pace, but rarely exceeded one hour.

Within the last week of the 15-week training period, post measurements were taken on all participants. All post measurements were collected prior to participation in the marathon or half marathon and were identical to the pre measurements.

CRP ANALYSIS

Resting blood draws (20 mL) were taken into EDTA vacutainers by a registered nurse before and after the training period. All samples were collected during the hours of 5am to 9am

after an overnight fast. Participants were required to perform a 1-day diet control, where they ate the same self-selected meals, during the 24 hours before blood sample collection to limit potential diet-induced alterations. The samples were cooled and the plasma was separated in a centrifuge for 10 minutes spinning at a rate of 1000 r.p.m. at 4°C. Then, the plasma was obtained and stored in a freezer at -80°C until the date of analysis. Once all plasma samples were collected, enzyme-linked immunosorbent assay (ELISA) kits (Alpco C-Reactive Protein (hsCRP) EIA, Salem, NH) were utilized to determine circulating levels of C-reactive protein (CRP). These values were obtained with a BioTek microplate reader (BioTek Instruments, Model MQX200, Winooski, VT.).

CARDIORESPIRATORY AND STRENGTH FITNESS TESTING

Aerobic capacity was determined by using a common field test equation used to estimate VO_2 max in which a 1.5 mile run time is inserted into the formula (24). The subjects performed a 1.5 mile run to the best of their ability before and after their training period. The test was conducted on an indoor track in order to keep environmental conditions constant. The 1.5 mile run test allowed for an estimate of each participant's maximal oxygen consumption (VO_2 max).

For those subjects in the ER group, an 8RM on bench and leg press was performed before and after their training intervention in order to determine potential gains in strength. As with every lift performed by the ER group throughout the course of the study, all 8RM lifts were supervised by an expert in the physical training field.

ANTHROPOMETRY

For purposes of accuracy, dual energy X-ray absorptiometry (DXA) was performed (Full-size Lunar Prodigy Pro, GE Lunar Corporations, Madison, WI) with the use of Encore 2004 software

(version 8.10.027) to measure total body fat percentage, regional body fat percentage, and lean tissue mass. The scan was conducted by a certified and skilled technician. A separate technician, not directly affiliated with the study, performed checks on the scans in order to assure validity and reliability.

Height and weight was recorded in order to calculate body mass index (BMI). Height was assessed using a stadiometer while weight was read from a digital scale. Waist and hip circumferences were measured with a Gulick tension tape and were then used to calculate the waist-to-hip ratio (WHR).

Exercise can often affect the results of anthropometric as well as body composition data. Therefore, exercise within the 24 hours prior to all such measurements was not permitted.

DATA ANALYSIS

Pre and post data collection including anthropometric values, estimated aerobic capacity, body composition, and plasma CRP levels were all recorded and entered into computerized spreadsheets. Formulas were used to determine VO_2 max (3.5 + 483/1.5 mile run time (min)), BMI (body weight (kg)/height (m^2)), and WHR (waist circumference (cm)/hip circumference (cm)). All formulas used can be referenced to ACSM's Guidelines for Exercise Testing and Prescription (24).

Data was analyzed using a series of 3(group) x 2(time) repeated measures analyses of variance (ANOVAs) with repeated measures on the second factors. The ANOVA was conducted for each of the following dependent variables: estimated VO_2 max, BMI, WHR, total body fat percent and mass, android fat percent and mass, gynoid fat percent and mass, lean tissue mass, and plasma CRP levels.

Before the statistical analysis, all CRP values were log transformed into normalized units. This has become the most accepted method of expressing CRP data because it ensures normality and homogeneity of variance. The Tukey analysis was used post hoc to determine areas of significance. Significance was set at $P < 0.05$.

CHAPTER 4 RESULTS

Sixty subjects were enrolled into the study. There were two dropouts within the first week of the study due to schedule conflicts; so 58 participants were enrolled (Figure 2). Participants chose to participate in a half marathon (n = 6) or the marathon (n = 12) or the half-marathon + resistance (n = 3) or the marathon + resistance (n = 8) groups. The active control (AC) group (n = 29) was recruited separately, one control for each training group participant. There were no significant differences among the groups and therefore, the groups were combined into the endurance (E) group (n = 18), which included both half and full marathon runners and the marathon + resistance (ER) group (n = 11), which included half marathon + resistance and full marathon + resistance groups. Adherence to the endurance training plans for both the E and ER groups was high. All participants from these groups were required to attend at least two group long runs each month and compliance for this was 100%. For the ER group's strength training sessions, compliance was 100%.

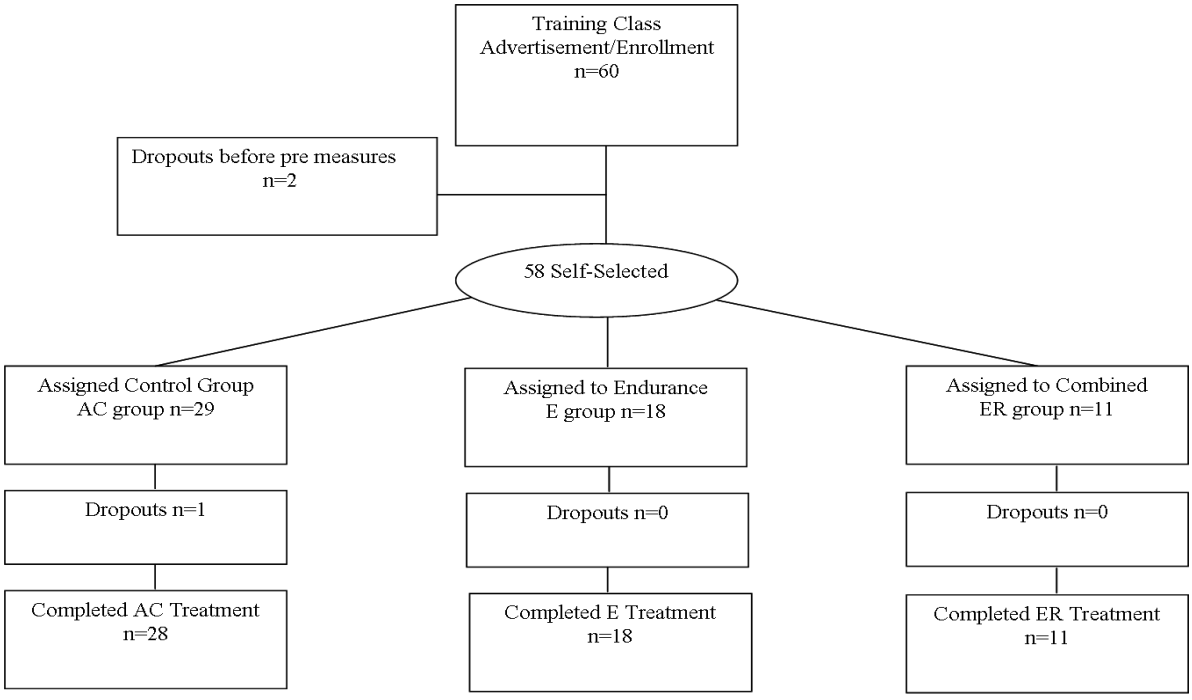

Figure 2. CONSORT diagram describing study flow.

There were no differences in CRP levels among the three groups at baseline. The E and ER groups tended to experience a reduction in plasma CRP levels over the course of the study, but none of these reductions were found to be statistically significant. Even though the reductions were only a trend, it is important to note that the ER group experienced a much higher average change from pre to post when compared to the E group. The average percent change was a 23.0% decrease in the E group and a 38.4% decrease in the ER group. The AC group experienced a 31.2% increase in CRP. A bar graph portraying these findings can be seen in Figure 3a. Figure 3b depicts the same results but with the more accepted CRP analysis using log transformation. This transformation failed to change the outcome.

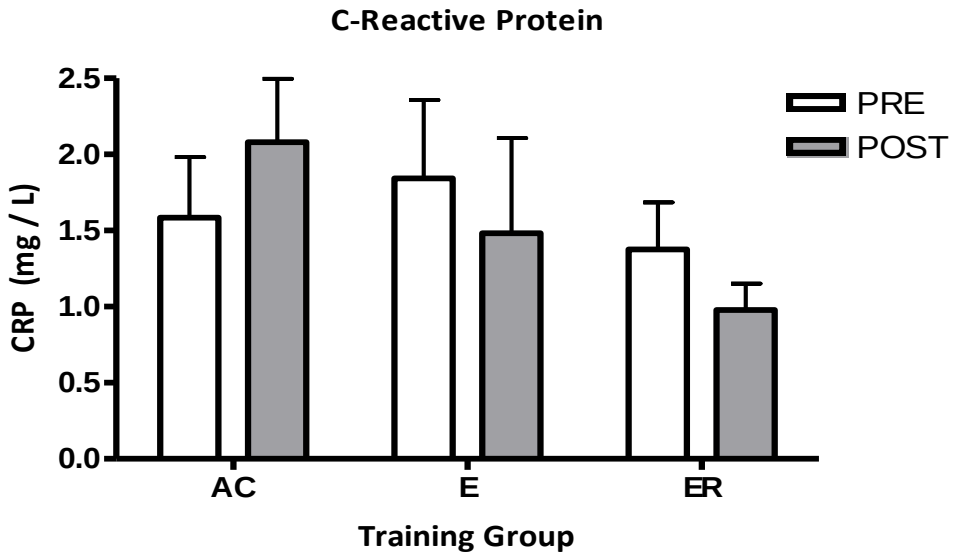

Figure 3a. C-reactive protein (CRP) at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.

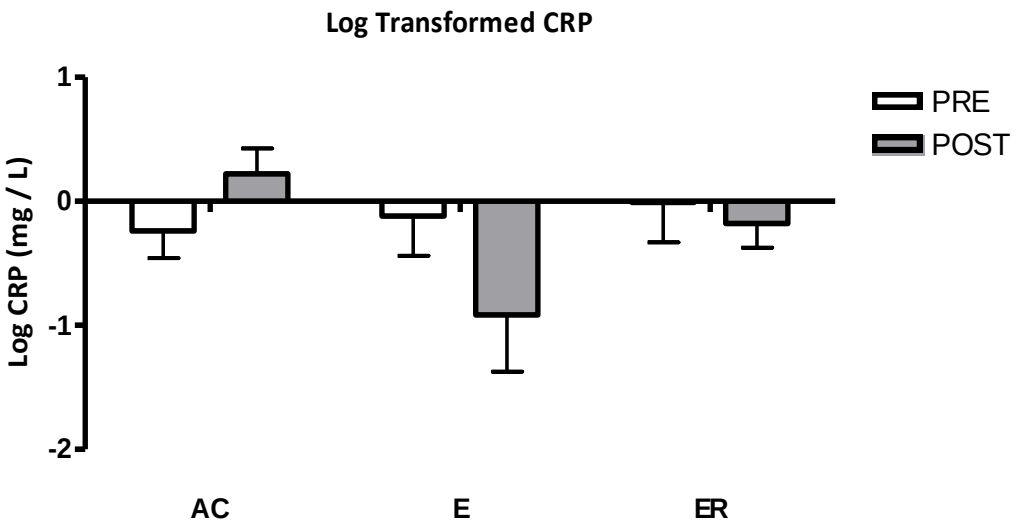

Figure 3b. Log transformed C-reactive protein (CRP) at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.

While there were no differences among the groups at baseline, there were changes in estimated VO_2 max (Figure 4) with training. The E group had the only statistically significant improvement in VO_2 max, increasing the average estimate from 38.9 ml/min/kg to 43.8 ml/min/kg with an average increase of 12.45% (P= 0.037).

Estimated VO_2 max was calculated from the 1.5 mile run completion time. There were no significant differences between groups at baseline for 1.5 mile time to completion. At the post intervention time point, there was a trend for improvements, but none of the changes were statistically significant. Despite the significant improvement observed for estimated VO_2 max in the E group, the 1.5 mile run time changed 8.5% from 13.57 ± 1.3 to 12.41 ± 2.7 minutes (mean ± SD), which did not reach significance ($P > 0.05$). Then with smaller and still insignificant improvements, the ER group decreased their average completion time from 12.72 ± 1.4 to 12.16 ± 1.3 minutes (mean ± SD) and the AC group changed from 14.24 ± 1.7 to 13.31 ± 2.0 minutes (mean ± SD).

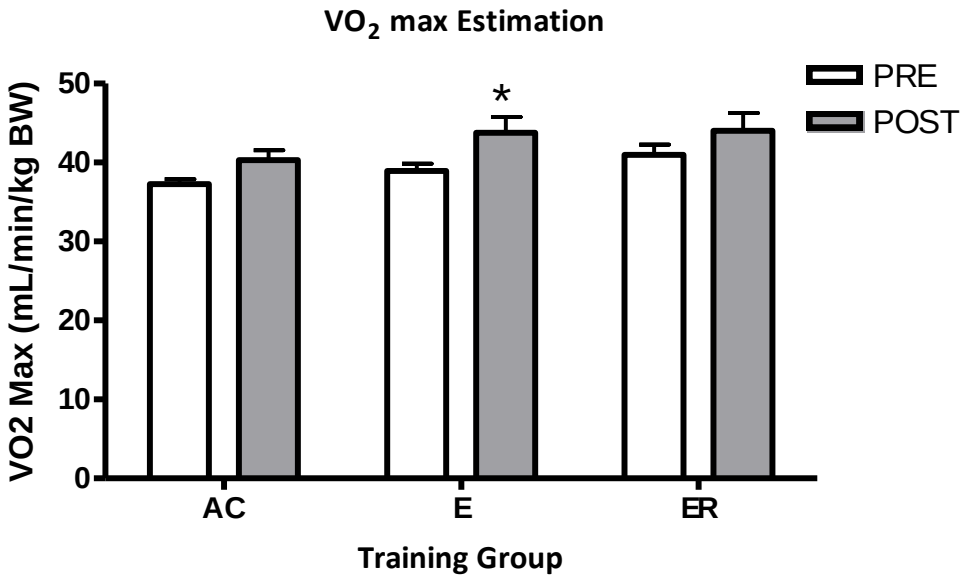

Figure 4. Estimated VO2 max at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.
* denotes significant change ($p<0.05$)

For the ER group only, a second performance measure was taken to determine strength gains with the addition of the RT intervention. The upper body strength gain determined by a bench press 8RM increased significantly from 65.0 ± 11.0 to 75.5 ± 13.1 lbs (average ± SD). This was a significant increase of 14.6% ($P < 0.05$). The 8RM leg press evaluated the lower body strength and increased from 98.0 ± 35.2 to 184.8 ± 48.7lbs (average ± SD) with an average 87.5% increase ($P < 0.05$) after the intervention period.

Table 4. Anthropometrics.

	Control (AC) Group		Endurance (E) Group		Endurance+RT (ER) Group	
	Pre	Post	Pre	Post	Pre	Post
Age	22.29 ± 2.40		22.44 ± 2.20		21.64 ± 1.03	
Height	66.30 ± 2.85		66.09 ± 2.52		65.45 ± 2.99	
Weight	146.9 ± 24.76	146.1 ± 25.67	138.9 ± 18.96	137.2 ± 18.86	140.8 ± 24.67	140.5 ± 22.30
BMI	23.39 ± 2.96	23.29 ± 3.08	22.30 ± 2.25	22.28 ± 2.69	22.94 ± 2.06	22.93 ± 1.78

The mean anthropometric measurements taken at baseline and at post intervention for all study participants are shown in Table 4. There were no significant differences in height, weight, or BMI at baseline or after the intervention.

Waist to hip ratio (WHR) was not significantly different at baseline among the three groups nor did it change significantly after the intervention period (Figure 5). Total percent body fat was not different among the groups at baseline, but decreased significantly in the E group only from 29.4% ± 8.3 to 27.7% ± 8.7 (mean ± SD) ($P = 0.037$). The percent change for this reduction in body fat was 1.7% (Figure 6). The ER group decreased percent body fat by 1.7% also, but the change was not found to be significant ($P > 0.05$).

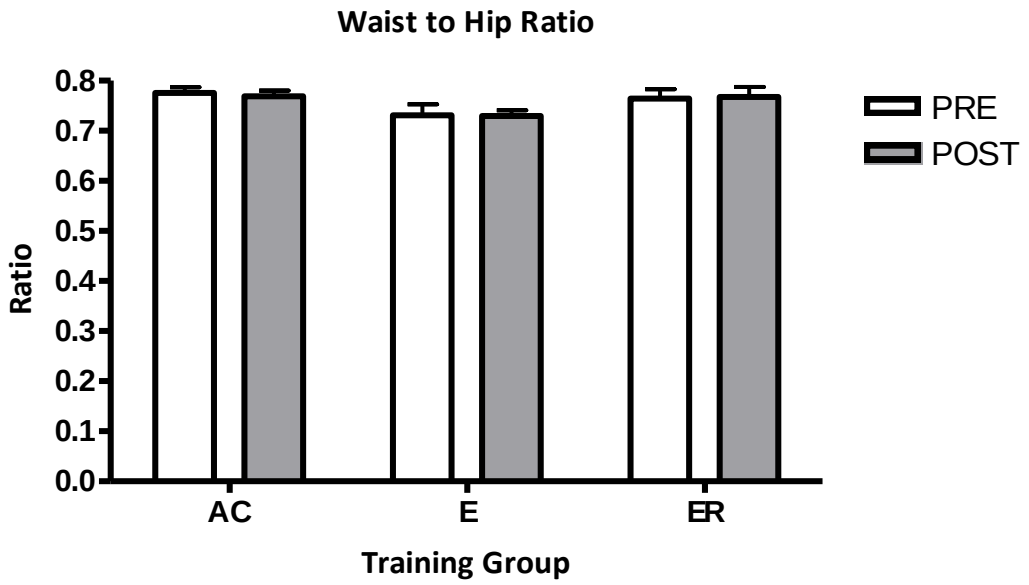

Figure 5. Waist to hip ratio at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.

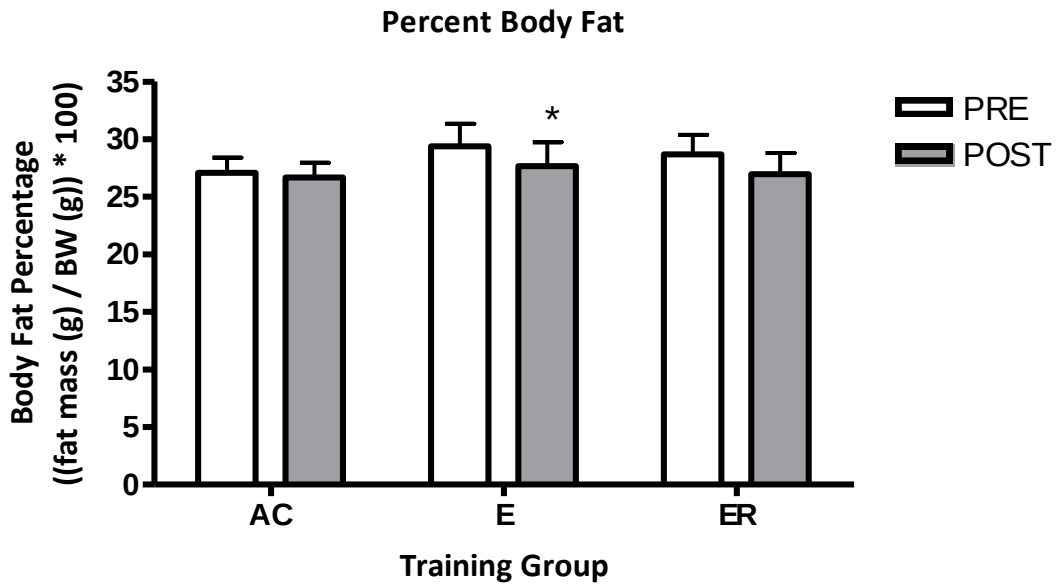

Figure 6. Total body fat percent at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.
* denotes significant change ($p<0.05$)

At baseline, there was no difference among the three groups for android or gynoid body fat. Then, following the intervention, no significant differences were noted for percent body fat or body fat mass in the android and gynoid regions. Overall, the E group decreased android fat by 2.4% and android fat mass by 11% while the ER group decreased android fat by 1.8% and android fat mass by 6% (Figure 7a and Figure 7b). In the gynoid region, the E group experienced a decrease in body fat by 1.8% and gynoid fat mass by 7.6% (Figure 8a and Figure 8b). The ER group experienced a 2% reduction in gynoid fat percentage and a 6.8% reduction in gynoid fat mass. It is important to note that the E group lost more body fat from the android region rather than the gynoid region while the opposite tended to occur for the ER group.

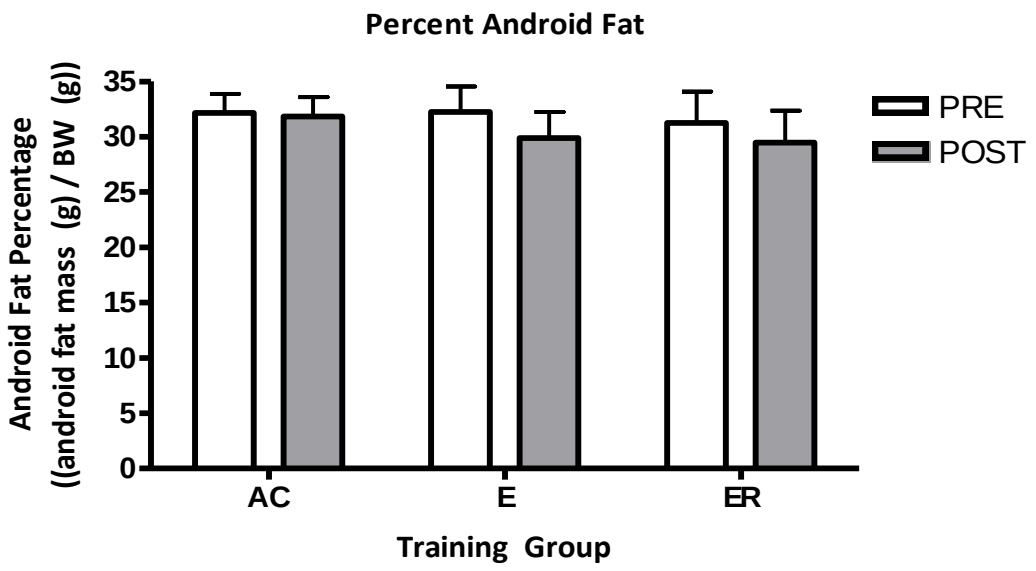

Figure 7a. Android fat percent at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.

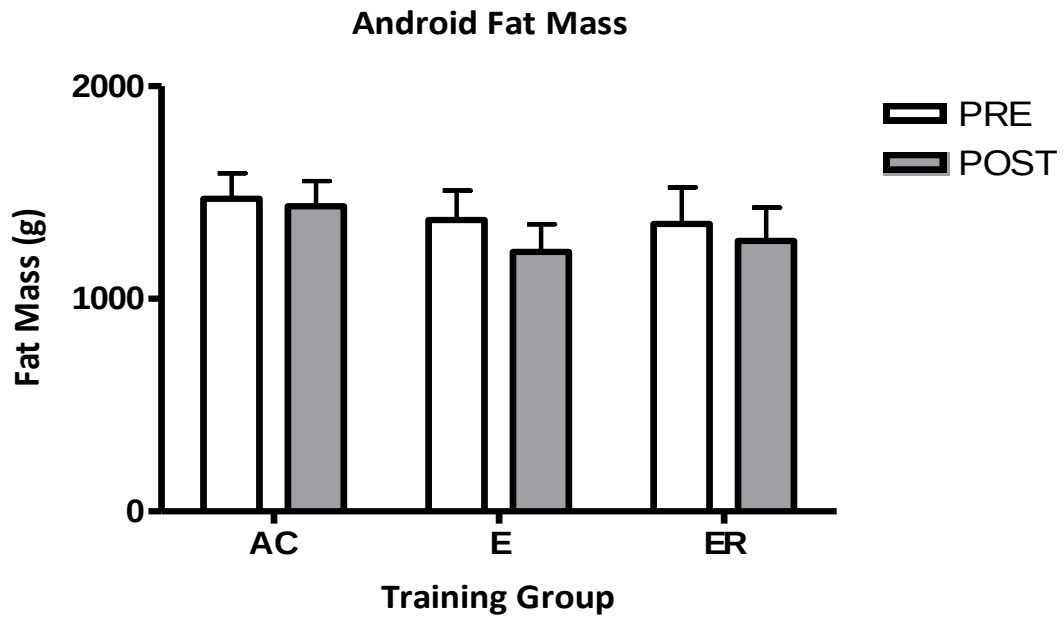

Figure 7b. Android fat mass at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.

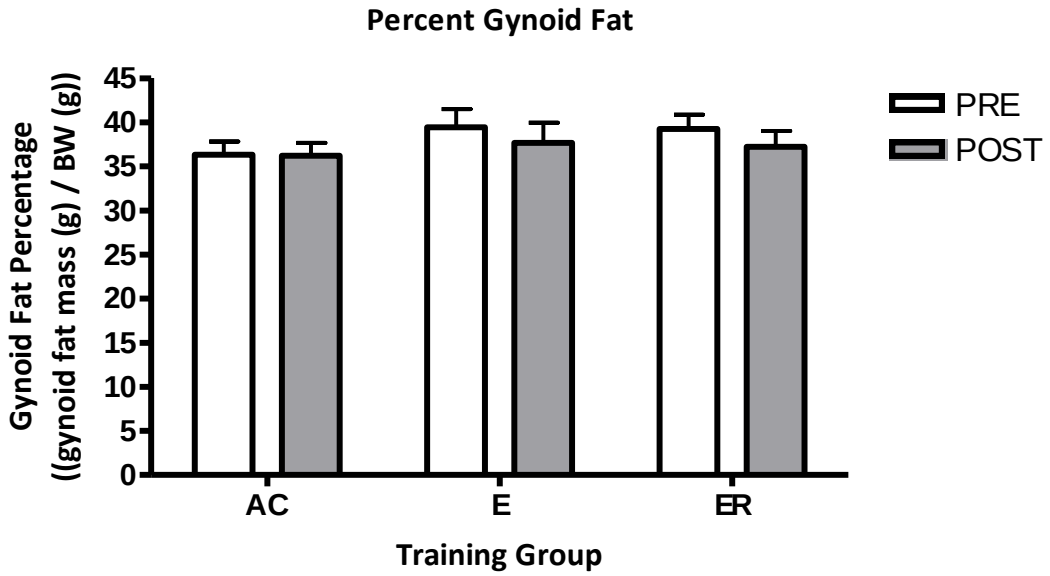

Figure 8a. Gynoid fat percent at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.

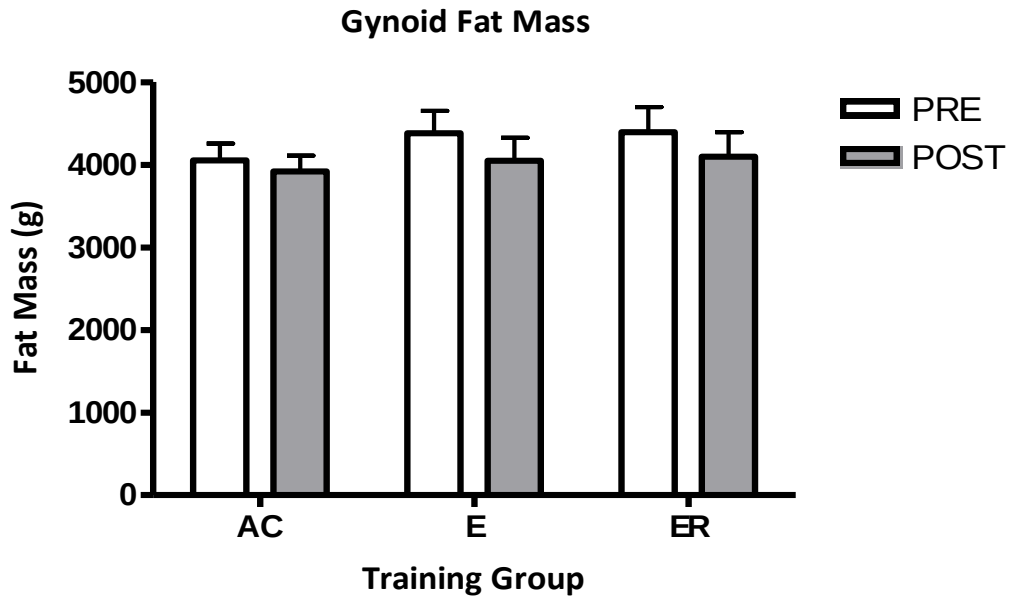

Figure 8b. Gynoid fat mass at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.

At baseline, there was no difference in lean tissue mass among the groups. After the intervention, the ER group experienced a 2.2% increase in lean tissue mass (Figure 9). While the

increase in lean tissue mass in the ER group was noteworthy considering the intense weight training plan, the change was not statistically significant. The AC group and E group had no significant changes in lean tissue mass.

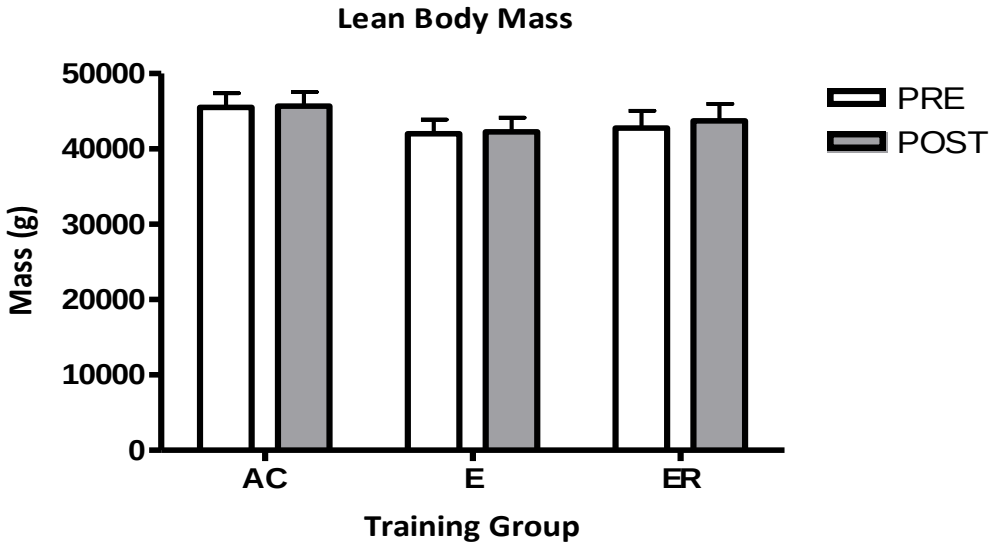

Figure 9. Lean tissue mass at pre and post intervention time points. Active control (AC) n = 29; Endurance (E) n = 18; Endurance + resistance (ER) n = 11.

At baseline and post intervention, total body fat and gynoid fat was highly negatively correlated with estimated VO_2 max ($P < 0.01$) (Table 5 and Table 6). As expected, most body composition measurements (body fat, fat mass, android and gynoid fat, lean tissue mass, BMI, WHR) were positively correlated with each other. At baseline only, CRP was moderately correlated with android fat ($P = 0.03$). However, this correlation did not show up as significant at the post intervention time point. In fact, due to the insignificant changes, there were no variables found to correlate with CRP after the intervention period.

Table 5. Relationship among all pre intervention measures.

	VO2	CRP	BMI	%BF	WST	HIP	WHR	AND	GYN	FM	LTM
VO2	1.000	0.045	0.211	-0.374**	0.256	-0.008	0.300*	-0.238	-0.417**	-0.180	0.477**
CRP		1.000	0.074	0.244	-0.017	0.029	-0.055	0.271*	0.201	0.168	-0.159
BMI			1.000	0.211	0.828**	0.647**	0.553**	0.464**	-0.013	0.585**	0.606**
%BF				1.000	0.086	0.297*	-0.112	0.879**	0.949**	0.875**	-0.540**
WST					1.000	0.612**	0.789**	0.394**	-0.150	0.472**	0.638**
HIP						1.000	0.001	0.508**	0.097	0.598**	0.457**
WHR							1.000	0.108	-0.253	0.139	0.441**
AND								1.000	0.712**	0.901**	-0.222
GYN									1.000	0.716**	-0.720**
FM										1.000	-0.090
LTM											1.000

Values are shown as Pearson correlation coefficients.

** correlation is significant at the $p<0.01$ level (highly correlated)

* correlation is significant at the $p<0.05$ level (moderately correlated)

Table 6. Relationship among all post intervention measures.

	VO2	CRP	BMI	%BF	WST	HIP	WHR	AND	GYN	FM	LTM
VO2	1.000	0.019	0.025	-0.451**	0.003	-0.220	0.233	-0.395**	-0.463**	-0.397**	0.305*
CRP		1.000	0.124	0.121	0.002	0.067	-0.065	0.165	0.162	0.108	-0.116
BMI			1.000	0.187*	0.869**	0.734**	0.503**	0.483**	0.065	0.629**	0.570**
%BF				1.000	0.160	0.531**	-0.276*	0.895**	0.948**	0.884**	-0.500**
WST					1.000	0.682**	0.719**	0.465**	-0.105	0.540**	0.685**
HIP						1.000	-0.015	0.678**	0.331*	0.770**	0.320*
WHR							1.000	0.000	-0.450**	0.018	0.637**
AND								1.000	0.741**	0.910**	-0.204
GYN									1.000	0.729**	-0.684**
FM										1.000	-0.068
LTM											1.000

Values are shown as Pearson correlation coefficients.

** correlation is significant at the $p<0.01$ level (highly correlated)

* correlation is significant at the $p<0.05$ level (moderately correlated)

CHAPTER 5 DISCUSSION

The primary objective of this study was to examine the effectiveness of endurance training vs. endurance + resistance training for reducing CRP. As a secondary objective, we further explored the relationship between exercise-induced changes in body anthropometry and aerobic capacity with CRP levels.

At baseline, we observed no statistical difference between treatment groups for any of the measured variables. Therefore, individual participant self-selection for each of the groups did not pose any problems. Initially, the participants enrolled in our study were able to choose whether they wanted to participate in a marathon or half marathon training plan and whether they wanted that training combined with a resistance training plan as well. The AC group was recruited separately. Given that no significant differences between the initial five groups existed, the groups were combined to form an endurance (E) group, an endurance + resistance training (ER) group, and the original control (AC) group. Combining the groups also allowed for a more acceptable number of participants within each group in order to obtain statistical power. It is important to note that when the half marathoners were removed from the analysis, so that only data from the marathoners and marathoners participating in the weight training program were included, the significance of the results was not changed. In addition, while there was a mixture of males and females in each group (AC group, M = 9 F = 20; E group, M = 3 F = 15; ER group, M = 1 F = 10), the focus of this study was not centered on identifying sex differences. Fortunately, the expected sex differences (weight, lean tissue mass, body fat, and BMI) did not create a problem since they were not found to be significant. Research has suggested that there may be a difference between CRP levels in males and females (6; 19). A

study by Vieira et al. showed that while it was merely a trend, females tended to have higher CRP levels at baseline and experienced statistically significant reductions in CRP at post exercise intervention (19). As a result, future studies focused on sex differences may provide beneficial information.

Both the E group and the ER group were given specific training regimens. Considering the high intensity of both the endurance and the resistance training plans, gains in fitness were expected. Although the baseline measures of fitness were not statistically different, it appears that the ER group may have started with a slightly higher level of fitness demonstrated by the approximately 5% higher estimated VO_2 max than the E group at baseline. This could explain why there were no significant increases in fitness level in the ER group. Interestingly, several reports also support our finding that when resistance training is paired with endurance training, the combination does not improve cardiorespiratory capacity more than endurance training alone (25). Specifically, Johnston et al. showed that when female distance runners were split into two groups, one of endurance training only and one of combined endurance and resistance training, there were no differences in VO_2 max between the two groups after the 10 week intervention period (25).

The significant change observed in the E group's fitness level suggests that improvements in fitness occur without a concomitant reduction in CRP. Specifically, no correlation was found between CRP and estimated VO_2 max after the intervention period ($P = 0.89$). It is possible that the lack of effect observed in the current study may be due to the participants being young, low risk, and healthy as all three groups had CRP levels in the average risk category (< 1mg/L (low risk), 1 – 3mg/L (average risk), > 3mg/L (high risk), none of which exceeded 1.8mg/L at baseline

(6; 26). Then, at the post intervention time point, the AC group experienced an increase to 2.1mg/L while only the ER group decreased into the low risk range with an average CRP level of 0.99mg/L. As other studies have shown, changes in fitness level are often associated with positive changes in CRP in both older and diseased populations (5; 17; 19; 21). Despite this premise, many of the studies involving such populations also had baseline CRP levels in the average risk range of 1 – 3mg/L, yet greater changes from pre to post intervention occurred.

Overall, decreases in CRP often occur along with improvements in fitness, body composition, or both. Both fitness and body composition generally deteriorate with age. This age-related worsening of fitness and body composition may account for the negative correlations between CRP and aerobic capacity and/or the positive correlations between CRP and body fat observed in other studies. The patterns found in the current study for reductions in CRP can be linked to other exercise interventions. In an endurance only training study by Mattusch et al., a small group of participants trained for a marathon over the course of 9 months and both aerobic capacity and circulating CRP levels were significantly improved. The trends found in this study for reduction in CRP can be linked to other exercise interventions. In an endurance training only study by Mattusch et al., a small group of participants trained for a marathon over the course of 9 months and both aerobic capacity and circulating CRP concentrations were significantly improved. Nine months of marathon training is more than twice the intervention period of our study (15 weeks) (27). Perhaps it can be speculated that greater improvements in CRP could have been seen with a longer training period.

Significant reductions in body fat occurred in the E group but not in the ER group. Both the E and the ER training plans were effective as demonstrated by improvements in the post 1.5

mile run completion times, indicative of a fitness gain. However, it is important to note that the participants in both the E and ER groups were able to choose their group rather than be randomly assigned. Those that chose to be in the ER group, an endurance program with very intense weight training, may have been more experienced individuals considering their slightly higher average estimated VO_2 max and a body fat percent that was 2.5% less than the E group at baseline. The changes found within the ER group for both body composition and estimated VO_2 max were not significant which, considering the duration and intensity of the intervention, supports the idea that these participants were already close to their fitness potential. At baseline, measures for estimated VO_2 max, participants in the E group were in the 20^{th} percentile for fitness as determined by the 2010 ACSM guidelines for men and the 55^{th} percentile for women (24). Participants in the ER group were in the 35^{th} percentile for men and the 70^{th} percentile for women (24). Given that there was a ratio of 10 women to 1 man in the ER group, these results suggest that the ER group was beginning the study closer to their fitness and body composition capabilities. To further support this stance, it should be noted that the first three participants to cross the marathon finish line during their race day were participants from the ER group.

According to recent literature, it is more common to find reductions in total body fat in line with reductions in CRP (16; 19). In our study, despite significant loss of body fat for the E group, CRP levels among all three groups were not significantly different at baseline nor were they significantly different after the exercise intervention. However, there were some noteworthy trends suggesting that both the E and ER training regimens lowered CRP, but that the ER regimen (endurance and resistance training) was more effective.

Given the link between CRP and regional body fat, this study also incorporated both percentages and absolute values of adipose tissue for the android and gynoid regions (19) (22). At baseline, there was a correlation ($P = 0.04$) between CRP and android body fat. The android region is considered to be the more unhealthy area for fat to accumulate due to its positive relationship with cardiovascular disease (28). At post intervention, the E group had a greater decrease in body fat from the android region when compared to the gynoid region. This is significant because a drop in the "unhealthy" region did not correlate with a drop in CRP values. Therefore, decreases in one risk factor for CVD do not necessarily entail a decrease in another. It is important to note that the measure of android fat taken in this study is different from the measure of visceral fat taken in the study by Kim et al. The android region as determined by DXA is the whole trunk region including visceral and subcutaneous fat, whereas visceral fat is only the intra-abdominal adipose tissue surrounding the organs in the lower trunk region.

STRENGTHS AND LIMITATIONS

This study had a few noteworthy strengths. All pre and post measurements were carried out just after the beginning of the training program or just before the end of the intervention period. All groups began and ended the study at the same time, which allowed for maximal organization and optimal participant motivation. The E and ER groups met twice each week throughout the training intervention. These meetings allowed the groups to stay motivated and obtain answers to any training-related questions. In addition, all long runs occurring on weekend days every weekend were performed in groups with a run supervisor. The ER group was consistently supervised in the weight training room and pushed to volitional fatigue. Every

participant from the ER group had a supervisor with them for each exercise ensuring both correct form and maximal effort. Both the E and the ER training plans were periodized and progressive in nature. Periodization allowed for optimal gains while progression allowed for easier adaptations.

There were several limitations discovered over the course of this study. The major limitation was the small number of participants in the (ER) group. However, a similar number of participants were found in other studies such as the marathon training study by Mattusch et al. in which the post intervention measures were taken on 12 runners and 10 controls (27). Also, all groups within our study contained both males and females. There were more females than males overall, but the difference in number of males compared to females was not significant (males=13, females=45). However, if the groups were split into males and females, the power was not high enough to determine sex differences. Another limitation was that all participants were young and healthy adults. Therefore, it was more difficult to see changes in variables that are often correlated with level of health, such as CRP. As mentioned before, the majority of research in the CRP field has been among the middle-aged and diseased populations. These populations often allow for more pronounced changes in CRP with various types of interventions. However, due to the fact that CRP level is highly predictive of relative risk for future cardiovascular events, this limitation can also be considered a strength because it allows for more available information about the ability of exercise to alter CRP levels in young people (6; 26). In addition, the inclusion of a fourth group, one in which the treatment was resistance training only, would have made this study more valuable. While it is helpful to see the differences between endurance groups with and without resistance training, an additional

group focused only on resistance training would have provided a definitive answer as to whether strength training alone can alter CRP and body composition. Also, to truly determine whether the strength gains seen for the ER group were due to the RT intervention, an 8RM should have been performed by the E and AC groups as well. Another limitation discovered was the inability to control diet among the groups. The only diet control that was administered was the one day diet control before blood samples were taken. A greater level of diet control may be helpful in determining whether changes in body composition are solely due to the training intervention. The final limitation for this project was that many of the AC group participants showed trends for positive changes in body composition and estimated VO_2 max suggesting that some of these participants increased their level of activity.

FUTURE DIRECTIONS

Future research addressing the link between exercise and alterations in CRP has many potential directions. More conclusive data is needed to fully determine whether resistance training can lower CRP levels. Studies that include endurance only and resistance only groups would be beneficial for this. Also, given the possibility for females to have higher CRP levels and a potential for greater CRP response to exercise interventions, attention should be given to differences among males and females (19; 26). It is interesting that the female participants in a study by Vieira et al. had baseline CRP levels higher than the male subjects since research has shown that males tend to have greater risk factors for developing CVD (29). It is important to note that the female participants in the Vieira et al. study also had a greater response to the intervention with a statistically significant decrease in CRP ($P = 0.028$) while the decrease for

the males did not reach significance. Furthermore, there is a need for more research involving CRP changes among different ethnicities. Given that CVD morbidity and mortality rates vary among races in the United States and Europe, there is reason to investigate a link between CRP and various ethnicities (6). A recent study by Heffernan exposed a possibility for differences between Caucasian males and African American males in which only the African American males significantly reduced their CRP levels after a 10 week resistance training program (30). There were no significant changes in body fat or cardiorespiratory fitness for any of the participants.

CONCLUSIONS

The primary finding of this study was that while both the endurance (E) group and the combined (ER) group showed trends toward lowering their CRP levels, neither group experienced significant changes in CRP after 15 weeks of intense training. There were significant reductions in body fat percent and significant increases in estimated maximal oxygen consumption in the E group only. Therefore, body composition and fitness level both changed significantly in the E group without great changes in CRP levels. The control (AC) group showed a trend toward increased levels of CRP, but this slight change was also found to be of no statistical significance.

In conclusion, the results of this study suggest that fitness and body composition may not be the only factors that influence CRP levels in healthy, young adult populations. While the training plans utilized for this study were effective in improving fitness and body composition in many of the participants, they failed to reduce CRP.

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VITA

Laura Daray was born in the fall of 1984, the youngest of three children, and was raised in Mandeville, Louisiana by her parents, Judy and Andy. Surrounded by family and numerous pets, Laura had a happy, stable childhood growing up in the wooded area around her home. Having two older brothers, she developed a love for playing sports, especially volleyball, and was involved in sports throughout junior high and high school. At an early age, Laura also discovered her talent for art, and enjoys painting the landscapes and wildlife of south Louisiana. Graduating high school as an honors student, she enrolled at Louisiana State University (LSU) in 2003. She was accepted into Phi Sigma Pi national honor fraternity her sophomore year and continued membership throughout the undergraduate program. Throughout college, Laura worked as a server at P.F. Chang's China bistro and as a personal trainer at Spectrum Fitness. She enjoyed coaching junior high girls' volleyball during this time as well. After completing a senior year internship at Pennington Biomedical Research Center in the spring of 2007, Laura earned a Bachelor of Science in kinesiology. Realizing her interest in the field, she applied for the exercise physiology master's program at LSU. Upon acceptance into the master's program, she began her own personal training business in Baton Rouge and still currently trains clients. Studying under her major professor Dr. Laura Stewart, Laura conducted her thesis project in the fall of 2008 with students from the LSU marathon training class. In preparation for the project, she ran a half marathon in April of 2008. However, due to limitations from a previous back injury, she searched for a more suitable and healthy form of exercise and therefore, currently participates in triathlons. Nearing the end of her graduate career, Laura accepted an assistantship allowing her to become project coordinator for the GeauxHeart Baton Rouge

community outreach project. Her duties involved coordination of health fairs and on-going communication with organizations such as the American Heart Association who donated educational materials to the project. She also trained students who took on the GeauxHeart project as an independent study course. Laura successfully defended her thesis in October of 2009 and will be awarded a Master of Science in kinesiology at the end of 2009.

Laura's future plans are currently undecided. She is considering a PhD program in hopes of becoming a professor as well as continuing research. Her fields of interest for a doctorate program include antigravity-related muscle atrophy generally associated with spaceflight and the emerging data on brown adipose tissue in relation to energy expenditure.