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PHYSIOLOGICAL RESPONSES TO COMBINED AEROBIC AND RESISTANCE TRAINING IN ELDERLY SEDENTARY MALES

BY

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TO CECIL HAYKOWSKY, FATHER, FRIEND AND MENTOR

ABSTRACT

Increased age is associated with a decline in [illegible] function resulting in a decline in muscle mass, muscular strength, maximal [illegible] power. Recent studies in the elderly have focused on improving [illegible] fitness through walking, jogging or running exercises. This type of training has been shown to improve maximal aerobic power, however it fails to address the muscular strength component of physical fitness which is reduced in the elderly. It has been suggested that the decline in maximal muscular strength and aerobic power may be due to an age related reduction in muscle mass. Based on these observations recent studies have [illegible]essed the effects of resistance training to increase muscular strength and muscle mass in the elderly. The purpose of this study was to assess if combined aerobic and strength training (CT) is more effective than aerobic training (AT) in improving maximal muscular strength, aerobic power and distance walked in six minutes, in sedentary males between 65 and 75 years of age.

After preliminary screening, subjects were randomly assigned to a CT (n=9) or AT (n=11) exercise group. Aerobic training was performed on a cycle ergometer at an exercise intensity equivalent to the heart rate at the Ventilation threshold ± 5 beats$\cdot$min^{-1}, three times per week for eight weeks. The strength training component of the CT groups exercise program was performed at an intensity equivalent to 40% of the pre-training one repetition maximum for three sets of 10-15 repetitions and increased by 5% every fourth session.

Post training analysis demonstrated that CT resulted in a significant increase ($p < 0.05$) in maximal oxygen consumption (10.8% l$\cdot$min^{-1}; 11.6% ml$\cdot$kg$^{-1}\cdot$min^{-1}), ventilation threshold (11.9%), maximal oxygen pulse (7%), knee extension 1 RM (21%), knee flexion 1 RM (51%), and distance walked in six minutes (5.7%). However, the increase in the above variables was not significantly different ($p > 0.05$) than that observed by the AT subjects post-training. The major finding in this study is that combined aerobic and strength training does not interfere with the improvement in maximal aerobic power but no more effective than aerobic training alone. The latter observation is similar to that observed for younger healthy individuals after concurrent exercise training.

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LIST OF ABBREVIATIONS

a-$\dot{v}O_2$ - arterial oxygen difference

EF - Ejection Fraction

HR_{max} - Maximal Heart Rate

HRR - Heart Rate Reserve

1 RM - One Repetition Maximum

O_2 $pulse_{max}$ - Maximal oxygen pulse

Q_{max} - Maximal cardiac output

SV_{max} - Maximal Stroke Volume

$\dot{V}O_{2max}$ - Maximal Oxygen Consumption

$\dot{V}eT$ - Ventilation Threshold

Chapter 1

1. Introduction

In Canada, the number of elderly individuals has tripled during the last forty years. Currently 11.6% of the population is 65 years of age or older and it is projected that by the year 2036 the number of elderly individuals over the age of 65 will account for 23% of the total population (Statistics Canada, 1991). Increasing age has been associated with a reduction in muscle mass, muscular strength, flexibility, walking speed, stride length, anaerobic power and maximal oxygen consumption ($\dot{V}O_{2max}$). The cause of the decline in physiological function has been attributed to the aging process, disease and disuse.

Previous research indicates that short (8 weeks) or long term (1 year) exercise interventions in the elderly have focused primarily on aerobic movements consisting of walking, jogging, running, rowing or cycling [Table 1] (Seals et al., 1984; Thomas, et al., 1985; Cunningham, et al., 1987; Belman and Gaesser, 1991). This type of training has resulted in a significant improvement in maximal stroke volume, arteriovenous oxygen difference, and $\dot{V}O_{2max}$ (Seals,et al., 1984; Thomas, et al., 1985; Cunningham, et al., 1987; Makrides, et al., 1990; Ehsani, et al., 1991; Govindisamy, et al., 1992). Despite the effectiveness of aerobic training to increase cardiovascular fitness in the elderly, this type of training fails to address the muscular strength component of physical fitness which has been observed to decline with advanced age.

The suggestion that the decline in $\dot{V}O_{2max}$ and muscular strength may be due to an age-related reduction in muscle mass has resulted in a few studies assessing the effects of resistance training to offset this decline (Tzankoff and Norris, 1977; Fleg and Lakatta, 1988; Frontera, et al., 1990) The paucity of data on strength training in the elderly reveals that this cohort can make appreciable (> 100%) increases in skeletal muscular strength after two months of training (Table 2). Hagberg and associates (1989) have suggested that strength training in the elderly may increase the peripheral aspects of $\dot{V}O_{2max}$ in those elderly individuals who have marked reductions in muscle mass and muscular strength. Frontera and colleagues (1990) have extended these observations and reinforced the finding that high intensity lower extremity resistance training can increase muscle mass, skeletal muscular strength and relative $\dot{V}O_{2max}$.

TABLE 1

INCREASE IN MAXIMAL AEROBIC POWER AS A RESULT OF EXERCISE TRAINING IN THE ELDERLY

Study	Duration (weeks)	Age (yrs)	Type of training	Frequency (days/wk)	Intensity (%HRR)	Duration (min/day)	Increase in $\dot{V}O_2max$
Badenhop 1983							
LI	9	67	CE	3	30-45	25	+16
HI	9	70	CE	3	60-75	25	+15
Belman 1991							
LI	8	68	WK	4	35	30	+7
HI	8	69	WK	4	75	30	+7
Govindasamy 1992							
	9	66	WK/JG	3	70-80% $\dot{V}O_2$	30	+12
Kohrt 1991							
HI	36-52	64	WK/JG/CE/RW	3	60-85	30-50	+24
CT	36-52	55	-	-	-	-	-
Makrides 1990							
YG	12	27	CE	3	85% HRmax	60	+29
OLD	12	65	CE	3	85% HRmax	60	+38
Posner 1992							
	16	68	CE	3	45	30	+8
Seals 1984							
LI-HI	52	63	WK	3	40-85	20-40	+30

(CE, cycle ergometer; CT, control group; HI, high intensity; HRR, heart rate reserve; JG, jogging; LI, low intensity; RW, rowing; WK, walking)

TABLE 2

IMPROVEMENT IN MAXIMAL MUSCULAR STRENGTH AS A RESULT OF RESISTANCE TRAINING IN THE ELDERLY

Study	Duration (weeks)	Age (yrs)	Type of training	Frequency (days/wk)	Sets	Exercise Reps	Intensity	Increase in Strength
Brown (1990)								
	12	63	AC/LP	3	2-4	10-15	70-90	48 (AC) 9 (LP)
Frontera (1990)								
	12	60-72	LE/LC	3	3	8	80	107 (LE) 227 (LC)
				(Cycle ergometer $\dot{V}O_{2max}$ increased+ 5% post-training)				
Fiatarone (1990)								
	8	90	LE	3	3	8	80	174 (LE)
Hurley (1984)								
	16	44	NT	3	1	8-12	HW	50 (UB) 33 (LB)
Kaffler (1992)								
	16	60	UB/LB	1 UB 2 LB	15 15	90 90	3 RM 3 RM	41 (UB) 48 (LB)
Panton (1990)								
	26	72	NT	3	1	8-12	HW	18 (UB) 9 (LB)
AT	26	72	WK/JG	3	50-80% HR max			6 (UB) 5 (LB)
CT	•	72	•	•	•	•	• •	- 7 (UB) - 6 (LB)

(AC, arm curls; AT, aerobic training; CT, control group, HW, sets performed with the heaviest weight possible; JG, jogging; LB, lower body; LC, leg curl; LP, leg press; NT, nautilus training; UB, upper body; WK, walking).

Despite the effectiveness of aerobic and resistance training to increase $\dot{V}O_{2max}$ and maximal muscular strength, respectively, a review of the related literature reveals that no attempt has been made to determine if an exercise regimen which combines both types of training is more effective in improving cardiovascular fitness and muscular strength than an exercise program consisting of aerobic exercise alone.

1.1 Statement of the problem

The main purpose of this investigation was to assess whether combined aerobic and strength training will improve lower extremity maximal muscular strength, walking distance and $\dot{V}O_{2max}$ to a greater extent compared to a routine consisting of aerobic training alone.

1.12 Hypotheses

In this study the following null hypotheses were tested at the $p < 0.05$ level of significance:

Primary hypotheses: There are no significant differences between pre and post training dependent measurements between the aerobic trained (AT) and the combined aerobic and strength trained group (CT). The measurements used for the primary hypothesis consist of body weight (kg), body mass index ($kg \cdot m^{-2}$), exercise test time (sec), peak power output (W), maximal O_2 pulse ($ml \cdot kg^{-1} \cdot beat^{-1}$), maximal ventilation ($\dot{V}e_{max}$), Ventilation threshold ($\dot{V}eT$), relative ventilation threshold ($\dot{V}eT \cdot \dot{V}O_{2max}$), $\dot{V}O_{2max}$ ($L \cdot min^{1}$) or $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$).

Secondary hypothesis: There are no significant differences between pre and post training measurements in the AT and CT groups for leg press, knee extension and knee flexion maximal muscular strength.

Tertiary hypothesis: There are no significant differences between pre and post test data for the AT and CT groups for the distance traveled during the six minute walk test.

1.13 Delimitations

1. The sample consisted of 20 male subjects between 65 and 75 years of age free from coronary artery disease as determined by medical history, baseline resting electrocardiogram and symptom limited graded exercise testing.

2. A sedentary lifestyle, defined as participation in regular physical exercise equal to or less then three times per week during the last six months prior to study participation.

3. The symptom limited graded exercise test was performed on a Siemans-Elma 380B cycle ergometer. Respiratory gas analysis was assessed by a Q-Plex Cardio-pulmonary exercise system.

4. Exercise training took place three times per week for eight weeks for a total of 24 sessions.

1.14 Limitations

1. The subjects were volunteers.

2. The degree to which the randomly selected sample of subjects represents the normal population of healthy sedentary males between 65 and 75 years of age.

1.15 Significance of the Study

Increased age is associated with a decline in cardiovascular and musculoskeletal function resulting in a reduced ability to perform various activity of daily living tasks. At the present time it remains unknown whether an intervention, such as resistance and aerobic training, which may have the potential to offset the decline in muscle mass, muscular strength and $\dot{V}O_{2max}$, can be more effective in increasing cardiorespiratory fitness and muscular strength than a regimen of aerobic training alone. The identification of an intervention which can offset the obligatory decline in physiological function will result in a growing number of elderly subjects who will be less reliant on the health care system in order to maintain a minimum level of functional well being.

1.16 Definition of Terms

Atrophy: Decrease in size of muscle tissue (Pate and Burgess, 1993).

Eccentric muscle contraction: Lengthening of a muscle as it develops tension (Pate and Burgess, 1993).

Detraining: *Termination of exercise training while maintaining normal day to day* activities (Nieman, 1990).

Hypertrophy: Increased size of an organ or tissue, usually caused by increased size of cells or tissue elements (Pate and Burgess, 1993).

Left Ventricular Ejection Fraction: An index of the extent of left ventricular shortening determined by the volume of blood ejected during systole compared with initial ventricular volume (Opie, 1991).

Maximal Aerobic Power ($\dot{V}O_{2max}$): The maximal rate at which an individual can take up, deliver, and utilize oxygen by the working muscles (Green and Patla, 1992).

Master Athletes: Individuals who train and participate in competition after the age of 40 years (Pollock, et al., 1987).

One Repetition maximum (1 RM): The greatest weight that can be lifted through a full range of movement for a muscle group (Nieman, 1990).

Radionuclide Angiocardiography: A non invasive technique used to assess left ventricular ejection fraction (Franklin, et al., 1993).

Sarcopenia: Age-related reduction in skeletal muscle mass (Evans and Campbell, 1993).

Chapter 2

Review of the Literature

This section reviews and summerizes the related literature regarding the reduction in cardiovascular and musculoskeletal function with aging and the effects of exercise to counteract this decline. This review will also attempt to find evidence which suggests that combined aerobic and resistance exercise may be of benefit for males between 65 and 75 years of age.

2.10 Decreased cardiovascular reserve with advancing age: confounding role of occult or overt coronary artery disease during senescence

Cross-sectional and longitudinal studies assessing the effects of the aging process on cardiovascular function are confounded by the finding that occult and overt coronary artery disease (CAD) become more prevalent during senescence (Rodeheffer, et al., 1984). A major limitation of studies assessing the effects of aging on cardiovascular function during exercise has been differentiating between the phenomenon associated with aging opposed to the phenomenon occurring secondary to disease.

2.11 Aging and myocardial function during maximal exercise

Aging is characterized by a reduction in cardiac reserve during exercise as demonstrated by a diminution in: maximal heart rate [HR_{max}] (Heath, et al., 1981; Hossack and Bruce, 1982; Rodeheffer, et al., 1984; Hagberg, et al., 1985; Higginbotham, et al., 1986; Pollock, et al., 1987; Ogawa, et al., 1992); maximal stroke volume [SV_{max}] (Hossack and Bruce, 1982; Rodeheffer, et al., 1984; Ogawa, et al., 1992); maximal cardiac output [Q_{max}] (Hossack and Bruce, 1982; Hagberg, et al., 1985; Higgenbotham, et al., 1986; Makrides, et al., 1990; Ogawa, et al., 1992; Lakatta, 1993); ejection fraction [EF] (Ehsani, et al., 1991); arteriovenous oxygen difference [a-$\dot{V}O_2$ diff] (Hagberg, et al, 1985; Makrides, et al., 1990; Ogawa, et al., 1992); and, maximal oxygen pulse [the product of SV and a-$\dot{V}O_2$ diff] (Heath, et al., 1981; Hagberg, et al., 1985). The reduction in cardiovascular reserve may contribute to the age-related reduction in maximal aerobic power.

2.12 Age-related decline in maximal aerobic power

Aging is associated with a decline in $\dot{V}O_{2max}$ (Robinson, 1938; Dill, et al., 1967; Robinson, et al., 1976; Heath, et al., 1981; Higginbotham, et al., 1986; Buskirk and Hodgson, 1987; Pollock, et al., 1987; Kasch, et al., 1990; Rogers, et al., 1990). In sedentary, healthy, non-exercise-trained individuals, $\dot{V}O_{2max}$ declines by approximately 10% per decade after the age of 25 years (Heath, et al., 1981; Rogers, et al., 1990). Physically active individuals who maintain a constant body weight during senescence have been shown to attenuate the decline in aerobic power by about 5% per decade (Heath, et al., 1981; Rogers, et al., 1990). The decline in cardiovascular function observed in healthy elderly individuals may be partially attributed to structural and functional changes in the cardiovascular system (Schlant, 1990, Lakatta, 1993).

2.13 Role of stroke volume, heart rate, cardiac output and arteriovenous oxygen difference in the age-related diminution in cardiac reserve

In the elderly, controversy exists regarding the role of the reduced Q_{max} and the reduction in $\dot{V}O_{2max}$. Ogawa et al. (1992) investigated the effects of age, sex, activity level and body composition on maximal aerobic power in 110 young and old healthy individuals. The age-related reduction in relative $\dot{V}O_{2max}$ (25-41%) in sedentary and athletic older individuals compared to younger activity matched controls was attributed to the reduced SV_{max}, HR_{max}, Q_{max} and maximal a-$\bar{V}O_2$ diff. Heath et al. (1981), and Hagberg et al. (1985), however, suggested that the decline in aerobic power in master athletes versus younger endurance-trained subjects was due solely to the reduced maximum HR. The difference in the reduction in $\dot{V}O_{2max}$ between master athletes and age-matched sedentary individuals has also been attributed to a decline in SV, and Q and a diminished oxygen extraction (Hagberg, et al., 1985).

The ongoing Baltimore Longitudinal Study on Aging provides evidence suggesting that Q_{max} does not decrease with age (Rodeheffer et al. 1984). The investigators assessed the acute cardiovascular responses during peak exercise in 61 males and females between 25 and 79 years of age and who were free from occult or overt CAD. No significant age-related decline in Q was observed during sub-maximal and maximal exercise. Rather, differences were noted regarding the mechanism with which Q was increased. Younger individuals relied on a greater HR and a lower end systolic volume while older individuals relied on the Frank Starling mechanism mediated by a greater end diastolic and stroke volume.

In summary, aging results in a reduction in HR, SV, Q and EF during maximal exercise. However, marked inter study variability has resulted in inconclusive evidence regarding the role of the central limitation in the age-related reduction in $\dot{V}O_{2max}$. The stimulus eliciting the reduction in cardiac reserve may be related to an alteration in the regulation between the sympathetic nervous system and the heart and vascular system.

2.14 Alteration in neuronal modulation of the heart and vascular system

Lakatta (1993) proposes that the age-related reduction in cardiac function may be related to an alteration in neuronal (Beta adrenergic) control of the heart and vascular system. Evidence for this theory is reinforced by a recent study by Stratton and associates (1992) who assessed the acute cardiovascular responses to graded isoproterenol infusions in young and old individuals before and after six months of aerobic exercise training. In the untrained state, older compared to younger subjects had a reduced HR, EF, Q, and systolic and diastolic blood pressure during isoproterenol infusions. The diminished cardiac reserve was not related to disuse-deconditioning, because exercise training did not alter the cardiovascular responses post exercise training in the older subjects. Because the subjects were screened for occult CAD, the observed results suggest that age-related perturbations in cardiovascular function may be due to a reduced efficacy of Beta adrenergic modulation on the heart.

2.15 Similarities between inactivity, disuse and aging on cardiovascular function

The consequences of a sedentary lifestyle mimic certain age-related alterations in cardiovascular function. This suggests that the decline in aerobic power during senescence may be secondary to disuse or deconditioning. Saltin and associates (1968) examined the effects of immobilization on various cardiovascular parameters in five healthy individuals. After twenty days of strict bedrest, maximal aerobic power decreased by 28% (range 20-46%) attributed to a similar decrease (26%) in maximal Q. This reduction was due solely to the reduced SV, as HR and a-$\dot{V}O_2$ diff were unaltered after bedrest. The reduced $\dot{V}O_{2max}$ after three weeks of bedrest was equivalent to approximately 20 years of aging (Evans and Rosenberg, 1991).

Physically active individuals experience marked reductions in cardiovascular function after a period of inactivity. Coyle et al. (1984) assessed the effects of 12 weeks of detraining on cardiovascular function in a group of highly trained athletes ($\dot{V}O_{2max}$ 62 $ml \cdot kg^{-1} \cdot min^{-1}$) who had participated in regular physical exercise for an average of ten years. Compared to the trained state, three weeks of inactivity resulted in a significant 7% decline in maximal aerobic power associated with a reduction in estimated Q and SV, respectively. The decline in aerobic power from weeks 3-12 was due to the diminished a-$\dot{V}O_2$ diff. The combined effects of aging and a sedentary lifestyle may lead to a reduction in muscle mass which has recently been implicated as a factor leading to the decline in $\dot{V}O_{2max}$.

2.20 Alteration in skeletal muscle morphology with age

A distinct feature of the aging process is the progressive reduction in skeletal muscle mass (Lexell, et al., 1983; Young, et al., 1984; Flegg and Lakatta, 1988; Vandervort and McComas, 1986; Rice et al., 1989; Frontera, et al., 1991; Aoyagi and Shephard, 1992; Lexell, 1993) associated with a concomitant increase in non-muscle tissue (Rice et al., 1989; Overend, et al,. 1990). An estimated 40% reduction in vastus lateralis muscle volume occurs between 20-80 years of age. The decline begins as early as 25 years of age and continues to the extent that by the eighth decade approximately half of the muscle volume is lost (Lexell, et al., 1988). The age-related decline in muscle mass, recently defined by Evans and Rosenberg as sarcopenia (1991), may be due, in part, to a reduction in muscle fiber size or number or a combination of both.

2.21 Sarcopenia: role of skeletal muscle atrophy

Skeletal muscle biopsy analysis of various upper and lower limb muscles reveals that skeletal muscle fiber size remains relatively constant until approximately the sixth or seventh decade of life during which time there is a reduction in the size of the type II (fast twitch), especially the type IIb (fast twitch glycolytic) muscle fibers (Aniansson, et al. 1980; Grimby, et al., 1982; Grimby and Saltin, 1983; Aniansson, et al., 1986; Gustavsson and Borges, 1986; Lexell, et al., 1988; Klitgard, et al., 1990; Aoyagi and Shephard, 1992; Rogers and Evans, 1993). Despite the observed reduction in type II muscle size, the time course of this adaptation remains heterogeneous between different muscle groups. Grimby et al. (1982) and Aniannsson et al. (1986) demonstrated that the muscle area for the types IIa and IIb fibers were smaller in the vastus lateralis than in the biceps brachii, while no appreciable difference was noted for the size of the type I (slow twitch oxidative) muscle fibers between these muscle groups.

The type I muscle fibers remain resilient during the aging process; no significant difference in the size of these fibers has been observed during senescence, compared to younger subjects (Larsson, Sjodin and Karlsson, 1978; Larsson, Grimby and Karlsson, 1979; Aniansson, et al., 1980; Anainsson, et al., 1986; Klitgaard, et al., 1990; Lexell and Downham, 1992). Lexell and associates (1988, 1992) have demonstrated that the mean area of type I fibers is not significantly altered between the ages of 20 and 80. The longitudinal study by Aniansson and associates (1986) extends the observations of Lexell, showing that the size of the type I muscle fibers does not change significantly over a seven year period in individuals between 73 and 83 years of age.

2.22 Reduction in the number of skeletal muscle fibers with age

With age the decline in skeletal muscle size was modest compared to the reduction in skeletal muscle mass, suggesting that the latter change may be due to an age-related reduction in the number of skeletal muscle fibers (Aniansson, et al., 1980; Grimby and Saltin, 1983). Unlike previous studies which have assessed the biochemical and histochemical analysis of single skeletal muscle biopsies, Lexell and associates (1983, 1988, 1992, 1993) used autopsy specimens to analyze the cross-sections of whole vastus lateralis muscle.

A comparison of the total number of fibers in the vastus lateralis muscle of young (30 years) and old (72 years) individuals revealed that an 18% decline in muscle fibers accounted for the age-related reduction in muscle volume (Lexell, et al., 1983). It has been stated that the decline in skeletal muscle fibers may begin at birth and continue to progress with increasing age (Grimby and Saltin, 1983). However, Lexell's 1988 study reveals that the loss of skeletal muscle fibers begins mid-way through the second decade, gradually decreasing until 50 years of age and accelerating thereafter. A recent review indicates that the decline in muscle volume associated with increased age was due primarily to the greater reduction in type II compared to type I muscle fibers (Lexel and Downham, 1992).

2.30 Decline in skeletal muscle strength with aging

Skeletal muscle strength measured during static or dynamic muscular contractions decreases with advancing age (Larsson, et al., 1979; Murray et al., 1980; Grimby and Saltin, 1983;, et al., 1986; and, 1986; Rice, et al., 1989; Overend et al., 1992;, et al., 1992; Rogers and Evans, 1993). The onset of the reduction occurs around 45 years of age and gradually decreases thereafter (Larsson, et al., 1979; Frontera, et al., 1991), culminating in an overall reduction of 30-40% during the course of one's lifetime. Skeletal muscular strength decreases concurrently with the loss of skeletal muscle fibers and muscle volume (Aoyagi and Shephard, 1992).

Several studies have illustrated that the maximal voluntary contraction of the knee and ankle flexor muscles are on average 37-55% lower in older (70-100 years) versus younger (20-35) individuals (Murray, et al., 1980; Vandervoort and McComas, 1986). The extent of the age-related decline in muscular strength depends on the type of contraction performed. Poulin and associates (1992) found a reduction in concentric and eccentric muscular strength with age. However the reduction during the latter contraction was slower than that of the former. No appreciable difference was observed during high velocity eccentric contractions. An attenuated decline in muscular strength during eccentric as opposed to concentric contractions was also demonstrated for the knee extensors after 30 days of head down (6°) bed rest (Dudley, et al., 1989). This reinforces the similarities between aging and inactivity.

2.40 Role of sarcopenia in the age-related decrease in muscular strength

The reduction in the number of skeletal muscle fibers combined with the selective atrophy of existing type IIb fibers may result in the observed decline in skeletal muscle strength (Grimby and Saltin, 1983; Lexell, 1993). A recent study by Frontera et al. (1991) provides evidence suggesting that the loss of strength with increasing age may be due primarily to the reduction in skeletal muscle mass. The investigators measured the isokinetic strength of the elbow and knee flexor and extensor muscles and normalized their values relative to fat-free mass and muscle mass (using creatinine excretion) in healthy males and females between the ages of 45 and 78 years. Absolute muscular strength was on average 19-23% lower in the older compared to the younger subjects. When muscular strength was related to muscle mass the observed age-related decline in strength was eliminated. Overend and associates (1992) observed a reduction in absolute knee flexor and extensor isometric strength between young and old individuals. However, no appreciable difference existed when strength was related to the cross sectional area of the hamstrings and quadriceps.

Vandervoort et al. (1986) and Brown et al. (1990) have demonstrated that the decline in strength in the elderly was not related to an inability to completely activate the respective motor units using the interpolated twitch procedure during maximal voluntary contractions of the dorsi and plantar flexors and elbow flexor and extensor muscles, respectively. Therefore, muscular strength relative to existing muscle mass was not appreciably different for the young and the old.

2.5 Role of Sarcopenia on Maximal Oxygen Consumption

Sarcopenia has been implicated as a factor leading to the decline in basal metabolic rate (Tzankoff and Norris, 1977) and maximal aerobic power (Fleg and Lakatta, 1988). During exercise, a large portion of oxygen consumed occurs in the working muscles. Therefore, it has been hypothesized that sarcopenia may account, in part, for the decline in $\dot{V}O_{2max}$ observed with aging. Fleg and Lakatta (1988) investigated the relationship between the loss of muscle mass (determined by creatinine excretion) and $\dot{V}O_{2max}$ in 83 physically active, non-endurance trained males and females. Aerobic power normalized to body weight decreased by 9.1% and 7.5%, per decade in males and females, respectively, while muscle mass declined by 6% per decade in both sexes. $\dot{V}O_{2max}$ normalized to total muscle mass markedly reduced the observed age-related decline in aerobic power.

Studies investigating the decline in aerobic power of competitive master athletes versus younger athletes matched for training intensity or best competitive performance suggest that factors besides sarcopenia may be the cause of the age-related decline in $\dot{V}O_{2max}$ in trained older athletes. Hagberg and colleagues (1985) compared $\dot{V}O_{2max}$ in master athletes, competitive young runners and young runners matched for exercise training and competitive race times equivalent to that of the master athletes. No significant difference in fat-free mass was seen between the three groups. $\dot{V}O_{2max}$ relative to body weight or fat free mass was significantly lower in the master athletes compared to either group of younger runners.

In summary, sarcopenia has been demonstrated to play a role in the decline in aerobic power with age, however the extent of this process may depend on the level of exercise training. Studies of master athletes suggest that sarcopenia cannot be the sole contributor to the decline in aerobic power with age. In sedentary deconditioned older individuals, the diminished muscle mass and subsequent muscular strength may result in peripheral fatigue before a central limitation effects the reduced $\dot{V}O_{2max}$.

2.60 Age-related decline in activities of daily living

Advanced age, especially after the seventh decade, has been associated with a reduced ability to perform various activities of daily living [ADL] (Jette and Branch, 1981; Lungren-Linquist, 1983a,b). Young (1986) and Astrand (1992) suggest that a large number of older individuals are living below a minimal threshold level necessary to perform ADL or do so with such effort that further diminution of function would result in greater physical dependency. The concept of a threshold level of strength or power required to perform ADL tasks was substantiated by Bassey and co-workers (1992) who showed that for elders between 80 and 99 years of age, the absolute minimal threshold necessary to rise from a chair unassisted, climb a flight of stairs 0.635m high or walk 6.1 m was $0.5 W \cdot kg^{-1}$. Moreover, it has been noted that individuals in their 80's must exert nearly 90-100% of their maximal quadriceps strength to sit up from a low chair unassisted (Young, 1986).

Evidence for the decline in ADL with age comes from the Framingham Disability study (1981) and the Longitudinal Study on Aging (1989). In the former investigation, comparison between younger (55 and 74) and older individuals (75 and 84) shows that a lower percentage of subjects in the older group are unable to perform heavy housework, walk a mile or climb stairs. Similar findings have been reported by Moir and associates (1989) who show that less then half of the subjects between 70 and 74 years of age in the Longitudinal study on aging cannot climb ten stairs, lift 11.3 kg, walk a quarter mile and perform heavy household work. The role of declined strength and power on age-related ADL deficits becomes more prominent when assessing the frail elderly. Bassey et al. (1988) examined the effects of age, strength of the gastrocnemius and soleus muscles with self-selected walking speed, and amount of customary walking in individuals 65 and over. In male subjects, calf strength was correlated with walking speed and amount of walking and was inversely related to age. Fiatarone et al. (1990) assessed the safety and feasibility of high intensity resistance training in institutionalized nonagenarians and found inverse correlation's between quadriceps strength and time taken to stand from a chair, six meter walk time and the number of steps taken during the latter test. The decline in ADL tasks as well as overall activity patterns may result in further deconditioning and disuse which may place these individuals at a greater risk for cardiovascular disease or all cause mortality Paffenbarger (1986).

2.61 Beneficial Role of Exercise in the elderly: Role of exercise therapy and the onset of cardiovascular disease and all-cause mortality

Paffenbarger et al. (1986) compared physical activity and lifestyle habits in 16,936 Harvard alumni to determine whether exercise could delay all-cause mortality. Over a sixteen year follow-up period, an inverse relationship was observed between physical activity and mortality. Males of all ages who expended >2000 Kilocalories (kcal) had a 28% decrease in all-cause mortality compared to less active counterparts (<2000 kcal). Blair et al (1989) have shown that daily walking for 30-60 minutes can reduce all-cause mortality.

Regular low intensity exercise initiated later in life can augment the time to onset of new cardiovascular disease. Posner and associates (1992) randomized 184 healthy individuals over 60 years of age into three groups: 1) a four month supervised training group who continued to exercise at home during a subsequent eight month period; 2) a short-term group who exercised in a supervised setting for four months; and, 3) an attention control group who met weekly for lifestyle enrichment discussions. Supervised and prescribed home exercise training was performed three times per week at a heart rate equivalent to 70% $\dot{V}O_{2max}$. The average time to onset of cardiovascular disease was 617, 715, and 728 days for the control, short term and long term groups, respectively. Despite the short and long term benefits of exercise, physicians have been reluctant to prescribe exercise for the elderly (Weachler et al., 1983), a finding probably related in part to a lack of knowledge by Doctors' regarding the benefits of regular physical fitness (Young, 1986).

2.70 Reversal of cardiovascular function during senescence: role of exercise

Regular physical training may offset the reduction in cardiovascular function associated with the aging process. Master athletes $\dot{V}O_{2max}$ declines by 5% per decade compared to a 10% decline in sedentary individuals (Heath, et al., 1981; Rogers, et al., 1990). Exercise initiated later in life has been demonstrated to alter cardiovascular function to the extent that the observed responses resemble that of a person twenty years younger (Khort, et al., 1992). The central and peripheral adaptations reported in the elderly after exercise training are similar to that observed for younger individuals.

2.71 Cardiovascular adaptations to exercise training in the elderly

Short (8 weeks) or long term (1 year) exercise training initiated later in life (60-80 years) results in a significant increase in: $\dot{V}O_{2max}$ (Seals, et al., 1984; Thomas, et al., 1985; Cunningham, et al., 1987); SV_{max} (Seals, et al., 1984; Ehsani, et al., 1991; Makrides, et al., 1990), Q_{max} (Ehsani, et al., 1991; Makrides, et al., 1990); a-VO_2 diff (Seals, et al., 1984; Makrides, et al., 1990); O_2 pulse (Hagberg, et al., 1989), Ventilation [$\dot{V}e$] (Seals, et al., 1984; Hagberg, et al., 1989; Govindasamy, et al., 1992); and, ventilatory threshold [$\dot{V}eT$] (Govindasamy, et al., 1992) with no change or a reduction in peak HR (Seals, et al., 1984; Govindasamy, et al., 1992). The magnitude of the relative increase in aerobic power (7-38%) is equivalent to that reported for younger individuals (Table 1).

2.72 Role of the central and peripheral adaptations in the observed increase in $\dot{V}O_{2max}$ with training

According to the Fick Equation, $\dot{V}O_{2max}$ is determined by the product of Q and a-$\bar{v}O_2$ diff. The precise role of the central (oxygen delivery) as opposed to the peripheral (oxygen extraction) component on the decreased $\dot{V}O_{2max}$ remains controversial in the elderly. This is due, in part, to the different methods used to observe Q (indirect vs direct) as well as the heterogeneity of the different exercise programs regarding training frequency, intensity and duration.

Seals et al. (1984) reported that the 30% increase in maximal aerobic power after one year of exercise training was due to an increase in a-$\bar{v}O_2$ diff because Q_{max} was not appreciably different from before training. The capacity of skeletal muscle to adapt to endurance exercise training was not diminished in the elderly. Master athletes have a significantly greater activity of mitochondrial enzymes: succinate dehydrogenase, beta hydroxyacyl CoA dehydrogenase and a larger capillary to fiber ratio compared to exercise matched younger controls (1990). The greater efficiency of skeletal muscle to extract oxygen during exercise may result in master athletes having similar performance times, compared to younger activity matched individuals, despite a lower $\dot{V}O_{2max}$.

Makrides and associates (1990) reinforced by Ehsani et al. (1992) have shown that the increased $\dot{V}O_{2max}$ with training was due to an increased Q_{max} and oxygen delivery. In the former study, subjects trained one hour a day three times a week for twelve weeks using an interval training routine equivalent to 65-124% of $\dot{V}O_{2max}$. The 38% improvement in $\dot{V}O_{2max}$ was accounted for by an increased SV_{max}, HR_{max}, and Q_{max}. Prolonged high intensity exercise training may alter the structural and functional characteristics of the aged myocardium resulting in enhanced systolic function. Ehsani et al. (1991) reported that a year long training regimen at an exercise intensity of 60-80 % $\dot{V}O_{2max}$ increased maximal aerobic power (28%), SV_{max}, Q_{max}

and EF_{max} without appreciable alterations in maximal a-$\bar{v}O_2$ difference. The enhanced SV during exercise was attributed to greater reliance on the Frank-Starling mechanism in part due to increased left ventricular size and to the increased myocardial contractility. The above research suggests that prolonged high intensity exercise training can elicit structural adaptations similar to that observed in younger athletic populations.

2.73 Physiological adaptations during sub-maximal exercise after endurance training

The physiological adaptations during sub-maximal exercise secondary to endurance training are similar in elderly and younger subjects. Exercise training results in a decrease in submaximal respiratory exchange ratio, blood lactate, $\dot{V}e$ and HR with no change or a decrease in mean, systolic or diastolic blood pressure. The decline in HR is offset by an increased SV resulting in no change in submaximal $\dot{Q}$ or $\dot{V}O_2$ (Seals, et al., 1984; Hagberg, et al., 1989). The rate of perceived exertion during sub-maximal exercise is decreased after exercise training allowing activities of daily living to be performed for a longer period of time.

2.80 Comparison between low and high intensity exercise training in the elderly

Exercise therapy may decrease all-cause mortality as well as offset the decline in various physiological processes. A question that remained debatable was the minimal intensity of exercise necessary to elicit these benefits in the elderly. Recent studies have confirmed that thirty minutes of low intensity exercise, 30-45% heart rate reserve [HRR], performed four times per week, for two to six months, can improve maximal aerobic power by 7-12% (Badenhop, et al., 1983; Seals, et al., 1984; Belman and Gaesser, 1991). A series of studies has recently shown that no appreciable difference in cardiovascular adaptations exists between low and high intensity exercise training regimens. Badenhop and associates assessed the effects of nine weeks of low intensity (LI) and high intensity (HI) exercise in elders over the age of 60 years (1983). The groups met three times per week and trained at an intensity equivalent to 30-45% and 60-75% HRR for the LI and HI groups, respectively. Maximal aerobic power increased in each group after training. However, no significant between group interaction was observed. Belman and Grasser (1991) reinforced the above findings in their examination of the effects of eight weeks of exercise training below (35% heart rate reserve [HRR]) and above (75% HRR) the lactate threshold in previously sedentary males and females (65-75 years).

The findings of Seals et al. (1984) support the hypothesis that maximal aerobic power can be improved during an HI regimen after previous exposure to LI training. Subjects exercised for six months at an exercise intensity equivalent to 40% HRR followed by a half year of HI training at 75-85% HRR. After LI training SV_{max} and relative $\dot{V}O_{2max}$ increased significantly by 6 and 12%, respectively. After the second period of HI exercise no appreciable difference was observed for SV_{max}, or Q_{max}. However, $\dot{V}O_{2max}$ increased by another 18%. Despite the enhanced physiological adaptations, it was revealed that a greater number of orthopedic injuries occurred during the latter phase. When dealing with the elderly a question that remains to be resolved is whether the benefits of training are worth the risks of injury in light of the finding that LI exercise can provide significant improvements in the related variables.

2.81 Resistance training in the elderly

Studies examining the effects of isometric, isokinetic, and isotonic weight training in the elderly revealed that older individuals skeletal musculature was amenable to resistance training interventions as evidenced by the marked increases in muscular strength and mass (Moritani and Devries, 1980; Aniansson and Gustafsson, 1981; Frontera et al., 1988; McCartney, et al., 1993; Roman et al., 1993). For example, it has recently been demonstrated that the untrained frail elderly persons can increase lower extremity muscular strength up to three fold after eight weeks of high intensity lower extremity resistance training (Fiatarone, et al., 1990). Despite the increase in strength it has been suggested that the mechanisms eliciting this response differs between the young and the old.

2.82 Increased muscular strength: role of neural adaptations versus muscular hypertrophy

Early resistance training studies proposed that the elderly lacked the ability to increase the size of their skeletal musculature, therefore the observed strength gains were due solely to neuronal adaptations. Moritani and Devries (1980) examined the effects of eight weeks of moderate intensity progressive resistance training of the elbow flexors in young (18-26 years of age) and old (67-72 years of age) males. Both groups displayed significant improvements in muscular strength after training. The mechanism eliciting this response differed between groups with the adaptations observed in the younger subjects being the result of both neural and muscular hypertrophy while in the elderly, neural factors accounted for the majority of the strength increases after training. Anniansson and Gustafsson (1981) assessed the effects of lower extremity resistance training for twelve weeks in males between 69 and 74 years of age. Muscular strength increased by 9-22% after training. However, muscle biopsy analysis revealed no appreciable quantitative alterations in muscle fiber area.

Recent evidence demonstrated that the capacity for muscular hypertrophy was retained in the elderly (Frontera, et al., 1988; Brown, et al., 1990; Fiatarone, et al., 1990; Roman, et al., 1993). Researchers from Tufts University assessed the effects of eight weeks of high intensity (80% 1 repetition maximum [RM]) progressive weightlifting training of the quadriceps and hamstring muscles in males between 60 and 72 years of age. Post training muscular strength increased by 227% and 107% for the knee flexors and extensors, respectively. Computer tomography analysis demonstrated a significant increase in muscle cross sectional area (11%), while muscle biopsy examination revealed hypertrophy of type I (33%) and type II (27%) muscle fibers (1990). Brown et al. (1990), corroborated by Roman et al. (1993), reported that the capacity of upper extremity musculature in the elderly to adapt to resistance training was similar to that noted for the lower limbs. A significant increase in muscle strength, elbow flexor cross sectional area and hypertrophy of fast and slow twitch muscle fibers was observed after resistance training.

Fiatarone and colleagues (1990) provide evidence that the physiological adaptations secondary to resistance training can occur in persons in the ninth decade of life. They assesed the effects of high intensity lower extremity resistance training in a group of institutionalized frail elderly (86-96 years of age). Muscular strength increased by 174% associated with a marked improvement in quadricep and hamstring strength after two months of exercise training at 80% 1 RM. The latter observations are of importance because an increase in muscular strength will require less of an effort to perform ADL tasks.

2.90 Role of exercise training to offset the age-related skeletal muscle morphology, muscle mass and strength

Klitgaard et al. (1990) have demonstrated that long term exercise training has the potential to offset the decline in skeletal muscle mass and may attenuate or obliterate the age-related diminution in skeletal muscle strength (1990). Individuals (69 years) who engaged in long term progressive resistance training were observed to possess comparable upper and lower skeletal muscular strength values as sedentary healthy younger (28 years) subjects. These findings suggest that resistance training initiated later in life may counteract the obligatory reduction in muscle strength that occurs with aging.

2.91 Role of resistance training to increase maximal aerobic power in the elderly

With the exception of circuit weight training (Fleck and Kramer, 1988), high intensity resistance exercise that produces increases in maximal muscular strength does not result in an increase in $\dot{V}O_{2max}$ in younger individuals (Hickson, et al., 1980). In older deconditioned individuals, who are limited during an exercise test by local muscular weakness and fatigue, high intensity resistance exercise may improve $\dot{V}O_{2max}$. Hurley and associates (1984) assessed the effects of 16 weeks of moderately high intensity circuit weight training exercise on aerobic power in 11 middle aged (40-55) individuals. The training resulted in a significant increase in upper and lower body strength of 50 and 33%, respectively. However, no appreciable difference in $\dot{V}O_{2max}$ was noticed. Hagberg et al. (1989) extended the observations of Hurley and assigned older individuals (70-79) into 26 weeks of endurance training, strength training or a non-exercise control group. After the program, no appreciable increase in maximal oxygen consumption was seen between the strength and control group, despite the former group's significant increase in upper and lower extremity strength. The endurance trained group increased their maximal oxygen pulse, $\dot{V}e$ and $\dot{V}O_{2max}$. These results supported by the findings of Hurley et al. (1984) underscored the lack of importance of strength gains on aerobic power.

A recent study by Frontera and colleagues (1990) contrast the above findings and suggests that high intensity lower extremity resistance training has the potential to increase maximal strength and $\dot{V}O_{2max}$. The 107% increase in knee extensor strength was associated with an increase in the mean fiber area of the vastus lateralis, number of capillaries per fiber, and citrate synthase activity. The end result of these adaptive physiological changes was a significant increase (6%) in relative $\dot{V}O_{2max}$. Therefore the potential for strength training to increase aerobic power in the elderly may be possible provided that the training intensity is relatively high.

2.92 Role of aerobic and weight training to increase maximal aerobic power

In this chapter, ample evidence is reviewed to indicate that aerobic and strength training routines can increase maximal aerobic power and muscular strength, respectively. A review of the related literature also reveals that a large number of studies in the elderly have assessed the effects of exercise training on maximal aerobic power (Table 1). Moreover, a few studies have assessed the effects of progressive resistance training in the elderly (Table 2.) An important question that remains unresolved is whether a regimen which combines both strength and aerobic training has the potential to increase maximal aerobic power than a traditional aerobic regimen alone. Such a combination can reasonably be expected to improve maximal aerobic power and muscular strength. This forms the basis for the investigation carried out in this study.

CHAPTER 3

METHODS

3.1 SUBJECTS

3.11 Preliminary screening

Subjects for this study were recruited from the greater Edmonton area through advertisements in seniors' homes and by a local newspaper (Appendix A). Criteria for selection for the study included the following:

1) Males between 65 and 75 years of age.

2) Absence of cardiac and orthopedic disease as determined by history, physical examination, resting and exercise electrocardiogram (ECG).

3) Sedentary lifestyle, defined as participation in regular physical exercise equal to or less than three times per week during the last six months prior to study participation.

Thirty-four subjects participated in the initial screening process and provided informed consent (Appendix B). During the initial assessment phase thirteen subjects were excluded from participating in the study. Eight of these subjects were excluded due to an abnormal ECG response to exercise; three subjects were unable to make the time commitment to the study; one subject had insufficient range of motion due to knee replacement surgery and another subject had never ridden a bicycle before and was unable to perform the baseline cycle ergometer test.

3.12 Study subjects

Twenty-one subjects were randomly assigned to eight weeks of aerobic training (AT) or combined aerobic and strength training (CT). Of the 21 subjects randomized one subject dropped out of the program after three exercise sessions because of increased fatigue associated with the training regimen. This study received ethics approval from the Institutional Review Board of Human Subjects at the University of Alberta Hospital. Descriptive physical data of the randomized subjects completing the study are presented in Table 3.

3.13 Initial screening and baseline testing

3.14 History, physical examination, baseline electrocardiogram and symptom limited graded exercise test

Subjects were initially evaluated by a Physician and Registered Nurse at the University of Alberta Hospital Department of Cardiology. During the initial visit a medical history, physical examination (Appendix C), resting ECG and symptom limited graded exercise test (SLGET) with simultaneous ECG monitoring and respiratory gas analysis were performed.

The SLGET was performed on an electrically braked cycle ergometer (Siemens-Elma 380B). The protocol consisted of one minute of seated rest followed by two minutes of unloaded cycling; thereafter the power output increased by 15 watts a minute at a pedal cadence of 60 revolutions per minute. During the test, continuous ECG monitoring of lead II, V1 and V5 were assessed; HR, BP and a twelve lead ECG were recorded every third minute of the SLGET and during recovery. Oxygen consumption was measured on a Q-Plex Cardio-pulmonary exercise system (Seattle, WA) to determine the $\dot{V}eT$ and $\dot{V}O_{2max}$. The SLGET was terminated at volitional fatigue or if one or more of the criteria (noted in Table 4.) were observed (Posner, et al., 1992). If an abnormal exercise response occurred, the subject was excluded from further participation in the study. Subjects excluded from the study were referred back to their General Practitioner with a letter regarding their initial participation along with their respective responses to the SLGET and reasons for exclusion.

3.15 Maximal lower extremity muscular strength and six minute walk test

Two days after the initial screening, subjects reported to the University of Alberta Van Vliet Centre and performed a six minute walk test and lower extremity maximal muscular strength assessments.

The six minute walk test was performed in the Universiade Pavilion along a 33m flat concourse. Subjects were instructed to walk from one end of the concourse and back again covering as much distance as possible in six minutes. Subjects were instructed that if they had symptoms of dyspnea, fatigue or pain that they could take intermittent breaks. At the end of the six minute period the test supervisor called out "STOP" and the distance traveled was measured.

Lower extremity maximal muscular strength was assessed following a one repetition maximum (1RM) protocol and defined as the maximum amount of weight that could be lifted through a full range of motion without breath holding, straining and using proper technique for one repetition. The 1 RM exercises tested included bilateral leg press, knee extension and knee flexion, respectively. The initial attempt for each exercise corresponded to the lowest weight on the respective machine and increased by 5 kilograms for the knee extension and flexion movements and 10 kg for the leg press. Subjects were given a 1-3 minutes rest between attempts.

The bilateral leg press 1 RM was performed on a universal leg press station. The subject was in the seated position with his knee joint flexed to 90 degrees with his back fully supported and feet resting on the foot plate. The movement began with simultaneous hip and knee extension with concomitant plantar flexion; the reverse action constituted one repetition. Knee extension and flexion 1 RM were performed on universal gym apparatus, respectively. In the former test the subject sat on the weight machine with the back supported and the knee joint at 90 degrees. The movement commenced with extension of the lower leg until the knee joint angle was at full extension (0 degrees) followed by reversal of the movement to the initial starting position. The knee flexion exercise began with the subject lying prone on the bench with the Achilles portion of the heel underneath the padded attachment. The subject flexed his lower leg until the knee joint angle corresponded to ~ 90 degrees reversing the above movement to the initial position.

3.16 Repeat testing

The SLGET, six minute walk, and maximal strength tests were performed twice with the second session scheduled one week after their initial assessment. If a discrepancy of one met (3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) occurred in SLGET or ± 5% in the strength or walking tests a third test was undertaken. The pre-training value used for statistical analysis was the highest score of the two baseline tests. In the event that a discrepancy between the two tests was observed the value obtained on the third test was used as the pre-training score.

3.17 Post training analysis

During the ninth week subjects reported to the University of Alberta Hospital Division of Cardiology exercise stress laboratory and performed a SLGET with ECG and respiratory gas analysis for re-assessment of their $\dot{V}O_{2max}$. Two days later subjects performed the six minute walk test and maximal muscular strength assessments. An additional test was undertaken during this session to assess absolute endurance on the leg press, knee extension and flexion. In each of the respective strength exercises subjects performed as many repetitions as possible with their pre-training 1 RM load.

3.18 Determination of $\dot{V}eT$ and $\dot{V}O_{2max}$

The ventilation threshold was determined by a systematic increase in the ventilatory equivalent for O_2 ($\dot{V}e \cdot \dot{V}O_2^{-1}$) without an increase in the ventilatory equivalent for CO2 ($\dot{V}e \cdot \dot{V}CO_2^{-1}$) [Ready and Quinney, 1982; Bhambani and Singh, 1985; Davies, 1985; Posner, 1986; Wasserman, 1987). $\dot{V}O_{2max}$ was defined as the highest $\dot{V}O_2$ obtained over a one minute period at volitional fatigue (Webb, Poehlman and Tonino, 1993).

3. 19 Exercise training protocol

The aerobic component of the exercise program for the AT and CT subjects was performed on Monark 818 and 818-E cycle ergometers . After a five minute warm up of low intensity cycling, the aerobic phase consisted of 15 minutes of continuous cycling at a HR equivalent to the VeT ± 5 beats. The duration of the aerobic phase increased by 2.5 minutes every fourth exercise session (Appendix D) and was followed by a five minute low intensity cool down. During the aerobic training, the HR of each subject was monitored continuously by means of a heart rate monitor (Polar Pacer, Port Washington, N.Y.).

After the completion of the cool down phase, the CT group went to the varsity weight room and performed three lower extremity exercises on the universal leg press, knee extension and knee flexion machines, respectively. The intensity of the resistance training corresponded to 40% of their 1RM for 10-15 repetitions for three sets and increased by 5% every fourth exercise session (Appendix D). Subjects were allowed to rest for approximately 1-3 minutes between sets.

Exercise training was performed in the University of Alberta Sport Physiology Laboratory and Varsity Weight Training facility and was supervised at all times by a Registered Nurse/Graduate Physical Education Student.

3.20 Statistical analysis

Statistical analysis for the primary, secondary and tertiary null hypothesis were performed with a two-way analysis of variance (ANOVA) with repeated measures. If a significant interaction was observed a post-hoc Neuman-Keuls test was undertaken. Comparison of the pre-training tests for $\dot{V}O2_{max}$, maximal muscular strength and distance covered during the six minute walk test were performed with a one way ANOVA with repeated measures. An unpaired t-test was used to determine if a difference existed between the two groups for lower extremity absolute endurance. A two tailed alpha level was set " a priori " at $p < 0.05$. All values reported are means ± (1 S.D.).

TABLE 3

PHYSICAL CHARACTERISTICS OF THE SUBJECTS

GROUP	AGE (YRS)	HEIGHT (CM)	BODY WEIGHT (KG)	BODY MASS INDEX ($kg \cdot m^{-2}$)	HEART RATE ($Beats \cdot min^{-1}$)	BLOOD PRESSURE SYSTOLIC	DIASTOLIC (mm hg)
AT	67.5 ± 3.1	174.7 ± 4.2	81.5 ± 9.5	26.7 ± 2.8	79.5 ± 12.3	133.1 ± 11.4	78.5 ± 9.9
CT	69.5 ± 3.0	174.2 ± 7.4	83.9 ± 12.5	27.8 ± 5.2	78.2 ± 10.1	145.1 ± 17.4	81.7 ± 8.2

(AT, Aerobic trained, CT, Combined trained; Values are means ± 1 S.D.)

TABLE 4

CRITERIA FOR TERMINATING THE GRADED EXERCISE TEST

1) Two or more frequent premature ventricular contractions (PVC'S)/min.

2) PVC'S of increasing frequency.

3) Multifocal PVC'S or ventricular tachycardia.

4) Second or third degree heart block or sudden left bundle branch block.

5) Significant ST segment depression or elevation.

6) Failure of pulse or blood pressure (BP) to rise during exercise; a drop in BP equal or greater than 10 mm Hg with exercise.

7) Subject unable to continue due to dyspnea, fatigue, dizziness, nausea, cyanosis, pallor or confusion.

8) Malfunction of equipment.

(Modified from Posner, et al., 1986).

Chapter 4

Results and Discussion

4.1 Results

4.11 Baseline Data

At baseline, the subjects in the AT and CT groups were not significantly different ($p > 0.05$) with respect to: age, weight, BMI, exercise test time, peak power output, $\dot{V}eT$, absolute and relative $\dot{V}O_{2max}$, $\dot{V}_{emax}$, HR_{max}, leg press 1 RM, knee *extension 1 RM, knee flexion 1 RM, and distance covered in the six minute walk test* (Tables 5-9).

4.2 Post training

4.21 Mean participation rate

The mean participation rate (defined as the number of sessions attended divided by the total number of required sessions) for all the subjects was 99%. One subject in the AT exercise group completed the required number of exercise sessions in six weeks because of a travel commitment. All exercise sessions were uneventful for orthopedic or cardiovascular accidents. During the post test resting portion of the SLGET, one individual in the AT group was observed to have a run of non sustained ventricular tachycardia. This participant was followed up with a Holter monitor. No serious adverse findings were noted and he was asked to continue his normal activities.

4.22 Duration of the aerobic and strength component of the training regimen

The average time spent in the aerobic portion of the exercise training was ~ 22.5 minutes, three times per week for all subjects. No significant difference ($p > 0.05$) was observed for the mean training HR during the aerobic portion between the AT [118.4(11.0) beats·min^{-1} equivalent to 77.6 (5.0) % pre HR_{max}] and the CT [116.3(9.1) beats·min^{-1} equivalent to 81.1 (7.7) % pre HR_{max}]. In addition, the CT group spent an extra 15-20 minutes per day, depending on the usage of the machines, in the University of Alberta varsity weight room to complete the strength component of the program. For all lower extremity exercises the CT subjects performed 3 sets of 10-15 (mean = 13) repetitions at ~ 57.5% of their pre-training 1 RM.

4.22 Body weight and body mass index

There was no significant change in body mass over the training period for either the AT or CT groups. Initial body weight was 81.5 (9.5) kg and 83.9 (12.6) kg for the AT and CT groups, respectively. Post training body weight for the AT group was 81.7 (9.7) kg and 83.2 (11.5) kg for the CT. BMI was not significantly different within or between groups after exercise training [initial: AT 26.7 (2.8) $kg \cdot m^{-2}$, CT 27.8 (5.2) $kg \cdot m^{-2}$; post training, AT, 26.7 (2.8) $kg \cdot m^{-2}$, CT, 27.6 (4.9) $kg \cdot m^{-2}$].

4.23 Test duration and peak power output during the symptom limited graded exercise test.

Exercise test duration increased significantly by 10.3% [initial: 867.3 ± (127.5) sec; post training: 956.4 ± (131.7) sec] in the AT subjects and 6.6% in CT group [initial: 840 ± (128.1) sec; post training: 895.6 ± (175.4) sec]. No significant difference was observed between the two groups for this variable after training (Table 5; Appendix F). Peak power output improved in the AT subjects by 13.2% ($p < 0.05$) while the CT group improved by 9.9% ($p < 0.05$). After training no significant difference was observed between the peak power output between the groups [(AT, 199.1 (32.9) W; CT, 185 (44.3) W, Table 5, Appendix F].

4.24 Maximal oxygen consumption, heart rate, oxygen pulse and ventilation

$\dot{V}O_{2max}$ increased significantly in both groups after eight weeks of exercise training (AT, 6.8% $L \cdot min^{-1}$ and 6.2% in $ml \cdot kg^{-1} \cdot min^{-1}$; CT, 10.8% in $L \cdot min^{-1}$ and 11.6% in $ml \cdot kg^{-1} \cdot min^{-1}$). Post training $\dot{V}O_{2max}$ values were not significantly different between the groups [$P > 0.05$] (Table 6, Appendix G). Maximal heart rate increased significantly ($p < 0.05$) after the 8 week training regimen in both exercise groups (Table 6, Appendix, G). Despite no significant difference post exercise training between the groups for maximal O_2 pulse, this variable increased ($p < 0.05$) for all subjects compared to pre-training values (AT, 3%; CT, 7%)[Table 6, Appendix G]. Maximal ventilation increased significantly after training in the AT [95.18 (16.01) $L \cdot min^{-1}$ to 109.73 (19.01) $L \cdot min^{-1}$] and CT subjects [94.44 (28.67) $L \cdot min^{-1}$ to 108.89 (36.18) $L \cdot min^{-1}$)[Table 6, Appendix G].

4.25 Ventilation threshold

After eight weeks of exercise training the power output at the $\dot{V}eT$ increased by 13% for all subjects ($p < 0.05$) [figure 1] resulting in a significant 10% improvement absolute $\dot{V}eT$ [initial: AT, 1.56 ± (0.29) $l \cdot min^{-1}$; CT, 1.59 ± (0.26) $l \cdot min^{-1}$; post training: AT, 1.70 ± (0.30) $l \cdot min^{-1}$, CT, 1.78 ± (0.33) $l \cdot min^{-1}$] (Table 7, Appendix H). The relative $\dot{V}eT$ [$\dot{V}eT \cdot \dot{V}O_{2max}^{-1}$] was not altered after exercise training [$p > 0.05$](Table 7, Appendix H).

4.26 Leg press, knee extension and knee curl 1 RM

Figure 2 demonstrates that leg press 1 RM did not change appreciably ($p > 0.05$) in the AT group after eight weeks of exercise training [initial, 150.91 (25.48)kg; post training, 153.64 (22.03)kg]. In the CT group leg press 1 RM increased by 13% (Table 8) after exercise training [initial, 161.11 (22.05)kg; post training, 182.22 (27.74)kg, $p < 0.05$]. The 18.6% difference in post training leg press 1 RM between the CT and AT groups was significant ($p < 0.05$) [Table 8].

Knee extension 1 RM increased significantly by 21% [initial, 44.96 (9.73) kg; final, 54.5 (8.76) kg, $p < 0.05$] in the CT after exercise training. Knee extension 1 RM was not significantly different ($p > 0.05$) from pre training in the AT subjects (Table 8, Appendix I). Knee flexion 1 RM increased significantly ($p < 0.05$) by 17.9% and 51% for the AT and CT groups, respectively, after the training regimen. No significant difference was noted for the post training maximal knee flexion strength scores between groups (Table 8, Appendix I).

4.27 Leg press, leg extension and leg curl absolute endurance

The CT subjects were able to perform a significantly greater number of repetitions with their pre-training 1 RM for the leg press, Knee extension and knee curl, respectively, compared to the AT group (Appendix J).

4.28 Six minute walk test

Distance covered during the six minute walk test for the AT subjects increased significantly ($p < 0.05$) from 526.66 (74.66)m to 540.20 (66.49)m equivalent to a 2.6% improvement. A 5.7% increase ($p < 0.05$) in walking distance was noted for the CT exercisers [526.33 (124.85)m to 556 (95.05)m]. No significant difference was noted between the distance traveled after training between the two exercise groups (Table 9, Appendix K).

TABLE 5

EXERCISE TEST DURATION AND PEAK POWER OUTPUT AFTER EIGHT WEEKS OF EXERCISE TRAINING

Parameter	Group	Pre-training	Post-training
Test Duration (seconds)	AT	867.3 ± 127.5	956.4 ± 131.7*
	CT	840.0 ± 128.1	895.6 ± 175.4*
Power Output (Watts)	AT	178.9 ± 32.2	199.1 ± 32.9*
	CT	168.3 ± 32.5	186.0 ± 44.4*

(Values are means ± 1 S.D.; AT, Aerobic training, CT, Combined training; * $P < 0.05$ pre vs. post training)

TABLE 6

EFFECTS OF EXERCISE TRAINING ON MAXIMAL CARDIORESPIRATORY MEASURES DURING THE SYMPTOM LIMITED GRADED EXERCISE TEST

Parameter	Group	Pre-training	Post-training
$\dot{V}e$	AT	95.2 ± 16.0	109.7 ± 19.0*
($l \cdot min^{-1}$)	CT	94.5 ± 28.7	108.9 ± 36.2*
O_2 pulse	AT	0.20 ± 0.03	0.21 ± 0.02*
($ml \cdot kg^{-1} \cdot beat^{-1}$)	CT	0.19 ± 0.05	0.21 ± 0.05*
HR	AT	152.6 ± 13.4	157.4 ± 16.1*
($beats \cdot min^{-1}$)	CT	143.2 ± 15.4	147.6 ± 20.1*
$\dot{V}O_{2max}$	AT	2.49 ± 0.4	2.66 ± 0.47*
($l \cdot min^{-1}$)	CT	2.31 ± 0.5	2.56 ± 0.59*
($ml \cdot kg^{-1} \cdot min^{-1}$)	AT	30.7 ± 5.1	32.6 ± 4.7*
	CT	28.5 ± 8.1	31.8 ± 9.8*

(Values are means ± 1 S.D.; AT, Aerobic training, CT, Combined training; * $P < 0.05$ pre vs. post training)

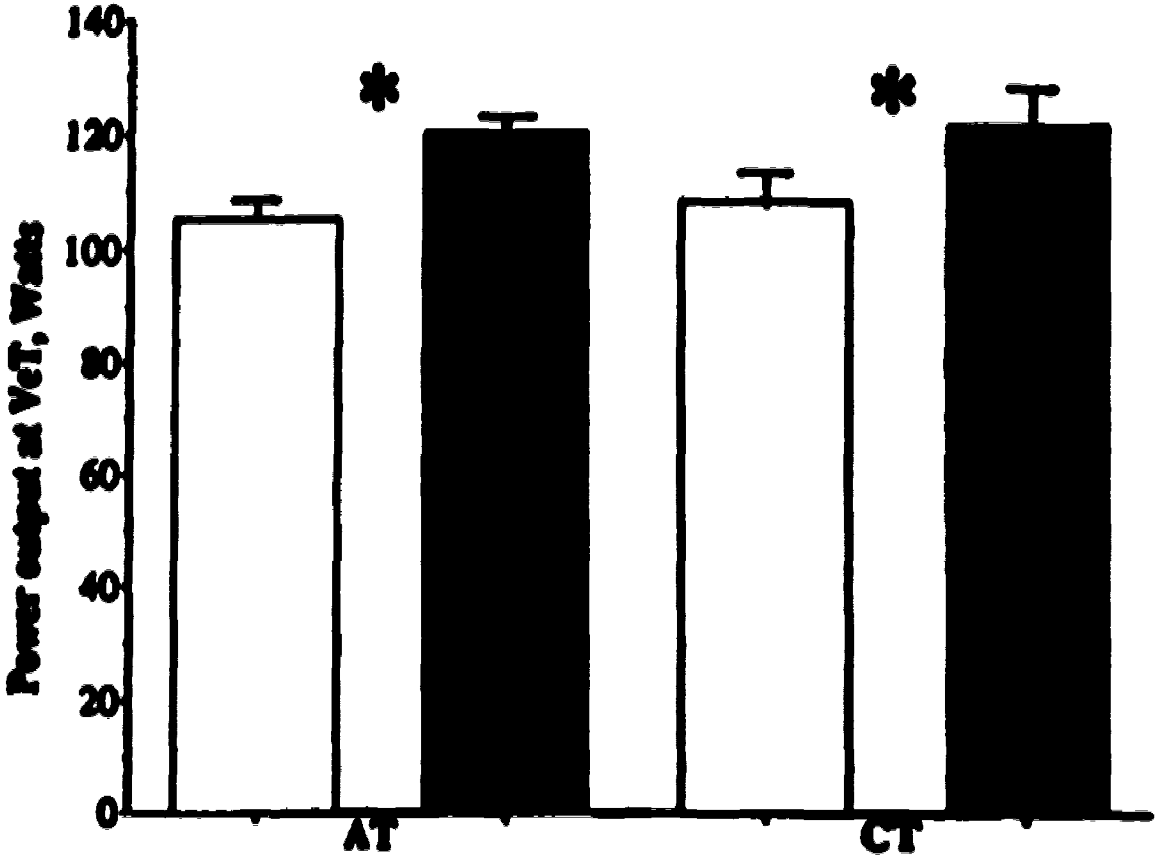

Figure 1. Power output at the VeT after eight weeks of aerobic (AT) or combined exercise training (CT). Values are means ± 1 S.E. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.

TABLE 7

ALTERATION IN THE VENTILATION THRESHOLD ($l \cdot min^{-1}$) AND RELATIVE VENTILATION THRESHOLD ($\dot{V}eT \cdot \dot{V}O_{2max}^{-1}$) AFTER EXERCISE TRAINING.

Parameter	Group	Pre-training	Post-training
$\dot{V}eT$	AT	1.56 ± 0.29	1.70 ± 0.30*
($l \cdot min^{-1}$)	CT	1.59 ± 0.26	1.78 ± 0.33*
$\dot{V}eT \cdot \dot{V}O_{2max}^{-1}$	AT	63.01 ± 8.43	64.32 ± 6.51
(%)	CT	70.12 ± 9.12	71.01 ± 10.98

(Values are means ± 1 S.D.; AT, Aerobic training, CT, Combined training; * $P < 0.05$ pre vs. post training)

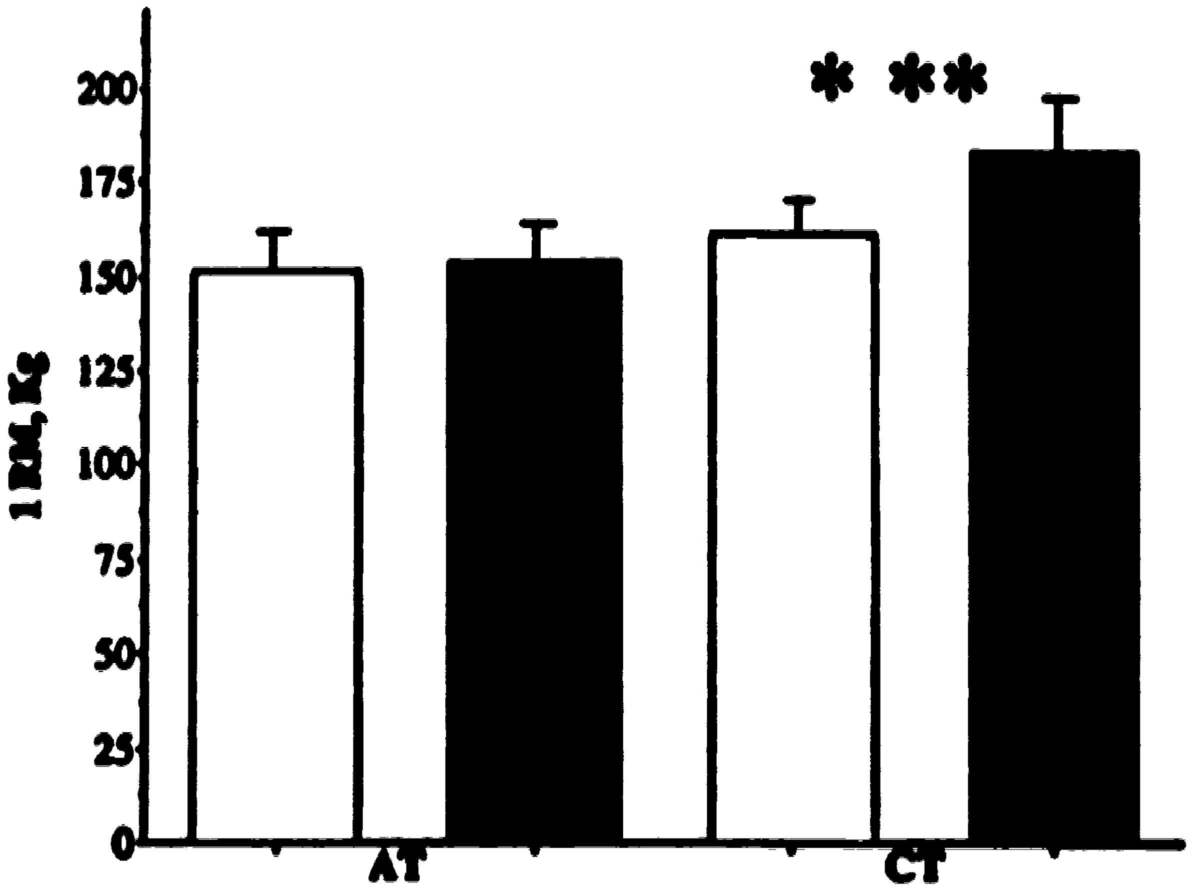

Figure 2. Leg press maximal muscular strength after eight weeks of aerobic (AT) or combined exercise training (CT). Values are means ± 1 S.E. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$; ** interaction CT > AT post training: $P < 0.05$.

TABLE 8

IMPROVEMENT IN LOWER EXTREMITY MUSCULAR STRENGTH AFTER EXERCISE TRAINING

Parameter	Group	Pre-training	Post-training
Leg Press (Kg)	AT	150.9 ± 25.5	153.6 ± 22.0
	CT	161.1 ± 22.0	182.2 ± 27.7* **
Knee Extension (Kg)	AT	45.1 ± 8.7	46.3 ± 9.0
	CT	44.9 ± 9.7	54.5 ± 8.7*
Knee Flexion (Kg)	AT	36.8 ± 10.8	43.4 ± 7.1*
	CT	33.4 ± 9.7	51.0 ± 11.3*

(Values are means ± 1 S.D.; AT, Aerobic training, CT, Combined training; * $P < 0.05$ pre vs. post training; ** $P < 0.05$ CT > AT)

TABLE 9

ALTERATION IN DISTANCE WALKED IN SIX MINUTES AFTER EXERCISE TRAINING

Parameter	Group	Pre-training	Post-training
Six minute Walk (meters)	AT	526.7 ± 74.7	540.2 ± 66.5*
	CT	526.3 ± 124.8	556.0 ± 95.1*

(Values are means ± 1 S.D.; AT, Aerobic training, CT, Combined training; * $P < 0.05$ pre vs. post training)

4.3 Discussion

Advanced age is associated with a decline in muscle mass, muscular strength, walking speed, stride length, $\dot{V}eT$, and $\dot{V}O_{2max}$ resulting in a greater effort to perform activities of daily living. Recent investigations have reported that low to moderate intensity (30 - 35% maximal heart rate reserve [HRR]) aerobic exercise performed three times per week for nine weeks can increase cardiovascular fitness by 7-16% (Badenhop, et al., 1983; Belman and Gaesser, 1991). Despite the marked improvement in cardiovascular function it has been suggested that the decline in $\dot{V}O_{2max}$ associated with aging is markedly attenuated when expressing maximal aerobic power relative to muscle mass. Based on these observations Frontera and associates (1990) have demonstrated that high intensity resistance exercise can improve lower extremity muscular strength and cardiorespiratory fitness. The purpose of this study was to extend the above observations and to determine if combined aerobic and strength training would improve $\dot{V}O_{2max}$, maximal muscular strength and walking distance, compared to a regimen of aerobic training alone.

With the exception of leg press 1 RM, the results indicate that the primary, secondary and tertiary null hypothesis cannot be rejected at the $p<0.05$ level of significance. The findings from this study suggest that combined training for aerobic and muscular strength does not interfere with the ability to increase $\dot{V}O_{2max}$, $\dot{V}e$, $\dot{V}eT$, exercise test time, peak power output, knee extension 1 RM, knee flexion 1 RM, and distance walked in six minutes. However, the magnitude of the increase in these variables is no greater then that induced by aerobic training alone. The finding that combined strength and aerobic training does not interfere with the improvement in $\dot{V}O_{2max}$, but no more effective then aerobic training alone, was similar to that observed in younger subjects [20-30 years of age] (Hickson, et al., 1980; Dudely and Djamil, 1985).

Figure 3. reveals that the initial level of relative $\dot{V}O_{2max}$ for the study subjects is similar to that observed by Heath and associates (1981) for age-matched untrained lean and overweight individuals. Our results suggest that previously sedentary males can make significant improvements in $\dot{V}O_{2max}$ after eight weeks of moderate intensity exercise training. These findings are in agreement with recent studies which have

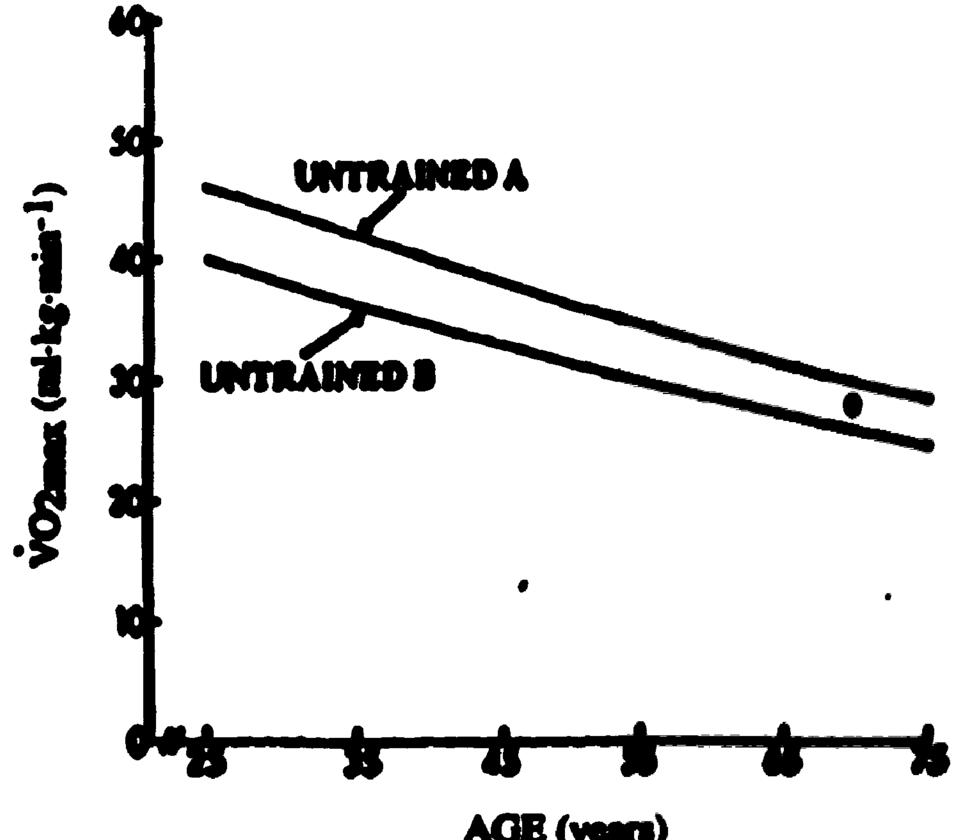

Figure 3. Age related decline in maximal aerobic power. (Untrained A, lean sedentary individuals; Untrained B, overweight sedentary individuals; Untrained A and B from Heath et al., (1981); • , average pre-training $\dot{V}O_{2max}$ for subjects in current study)

shown that short term low to high intensity (53-82% $\dot{V}O_{2max}$) aerobic exercise performed for 30-60 minutes three to four times per week can result in a 7-12% increase in $\dot{V}O_{2max}$ (Belman and Gaesser, 1991; Posner, et al., 1992; Poulin et al.,1992). Poulin and associates (1992) exercise trained a group of elderly males (mean age 67.4) for nine weeks at an exercise intensity similar to both groups in the current study and observed an 8 and 11% increase in absolute and relative $\dot{V}O_{2max}$, respectively. Other investigators have demonstrated that short (12-16 weeks) or long term exercise training (6 months - 1 year) in the elderly (> 65 years of age) can increase $\dot{V}O_{2max}$ by 21-38%. In those studies demonstrating marked improvements in cardiorespiratory fitness the subjects trained three days per week for ~ 40-60 minutes·day^{-1} at an intensity equivalent to 60-85% HRR. In the current study, the subjects exercised for ~ 23 minutes at a HR equivalent to 78-81% HR_{max}, three days per week for eight weeks. Moreover, the pre-training $\dot{V}O_{2max}$ for subjects in the study by Makrides and associates (1990), who reported the greatest increase in $\dot{V}O_{2max}$ [38%], was below 25 ml·kg^{1}·min^{-1}. Cunningham and associates (1987) confirmed that the greatest improvements in cardiovascular fitness occur in those individuals with an low initial $\dot{V}O_{2max}$; individuals whose $\dot{V}O_{2max}$ is below 25 ml·kg^{1}·min^{-1} are expected to increase their $\dot{V}O_{2max}$ by 25 %. The discrepancy between our findings and that noted by the above studies may be explained by differences in the length of the training program, intensity of exercise and pre-training $\dot{V}O_{2max}$.

Fleg and associates (1993), supported by data from Younnis et al. (1990), demonstrated that increased age is associated with a blunted cardiovascular response during exercise resulting in a reduced HR_{max} and maximal ejection fraction. During maximal exercise older individuals rely on an increased end-diastolic and end-systolic volume via the Frank-Starling mechanism to maintain cardiac output. The improvement in cardiorespiratory fitness observed by the AT and CT subjects can be attributed to central and peripheral factors. After the eight week training regimen all subjects had a significant increase in HR_{max} and O_2 $pulse_{max}$, an indirect measure of stroke volume and arteriovenous-oxygen difference. The enhanced chronotropic activity noted post exercise training for all subjects may be attributed to an augmented response to beta adrenergic stimuli resulting in a greater HR and myocardial contractility during peak exercise. Makrides and associates (1990) attributed the marked increase in $\dot{V}O_{2max}$

after exercise training to a greater HR_{max}, SV_{max} and Q_{max} with the increase in maximal a-$\bar{v}O_2$ diff playing a secondary role. Ehsani and associates (1991) extended these observations and reported that the increased $\dot{V}O_{2max}$ associated with one year of high intensity exercise training in a group of older subjects (60-70 years of age) was due to enhanced left ventricular systolic function resulting in an augmented inotropic state. Seals et al. (1984) contrasted the above findings by demonstrating that the 30% increase in maximal aerobic power after one year of exercise training was due to an increase in a-$\bar{v}O_2$ diff because Q_{max} was not appreciably different form pre-training values. Despite the limitation of not being able to determine the nature of the stimulus eliciting the enhanced maximal aerobic power, analysis of Figure 4. reveals that eight weeks of exercise training resulted in improvement in the current subjects cardiovascular status equivalent to that observed for individuals 5-20 years younger.

The pre-training absolute $\dot{V}eT$ for the CT and AT subjects in this study was 1.58 $L \cdot min^{-1}$ which is above the acceptable lower limit of 1 L $O_2 \cdot min^{-1}$ suggested by Wasserman and associates (1973). After exercise training the average increase in absolute $\dot{V}eT$ for all subjects is consistent with recent studies that reported an 11%-15% increase in this variable after short term exercise training (Blumenthal, et al., 1989; Belman and Gaesser, 1991; Govindisamy, et al., 1992; Poulin, et al., 1992). The average post-training $\dot{V}eT$ for all subjects (~ 6 mets) suggests that the subjects in the current study can perform activities of daily living such as walking 4 miles per hour, carrying heavy groceries, shoveling 10 lbs of snow for ten minutes or sawing hardwood at a comfortable pace without undue fatigue. Bellman and Gaesser (1991) suggest that exercise prescription in the elderly should be based on a parameter such as the lactate threshold rather then a percentage of HR_{max} or $\dot{V}O_{2max}$. They randomly assigned subjects to a low intensity group, who trained at an intensity ~ 72 % of the lactate threshold and a second high intensity group who exercised at ~ 121% LT. After the eight week exercise program the low intensity and high intensity groups increased their LT by 12% and 10% with no significant difference between groups for the change in this variable. The findings from the current study demonstrate that the $\dot{V}eT$ is a novel, safe, and effective method for setting exercise prescription in the elderly.

$\dot{V}O_{2max}$ and $\dot{V}eT$ decline with increasing age with the reduction in the former being greater then the latter resulting in the $\dot{V}eT \cdot \dot{V}O_2^{-1}$ being higher in elderly

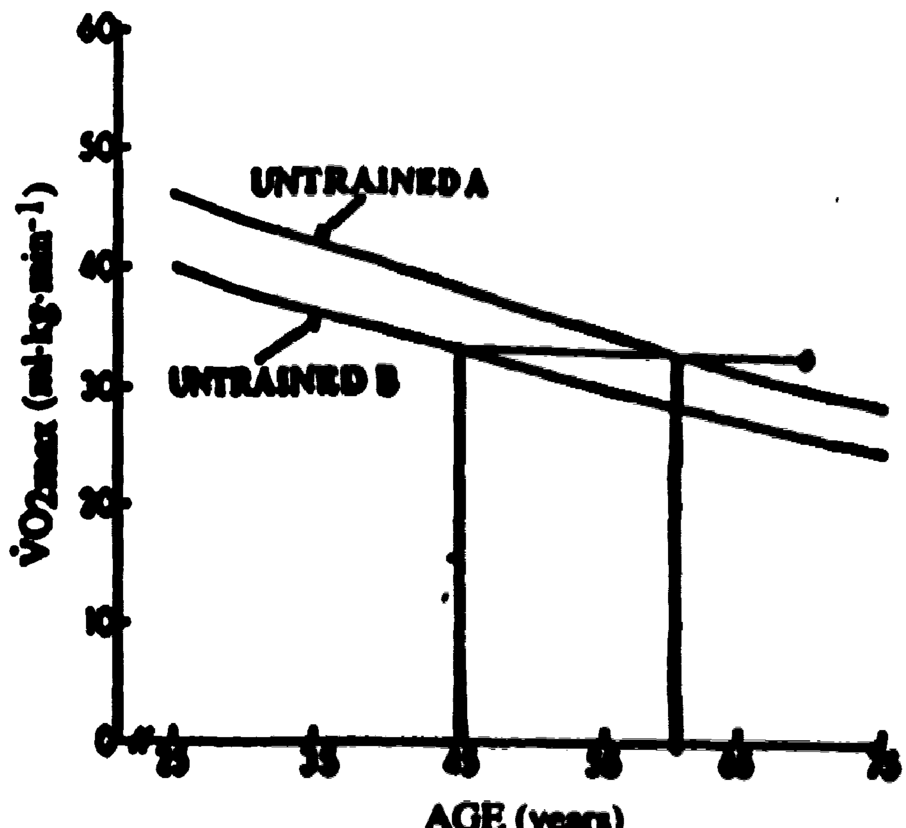

Figure 4. Decline in maximal oxygen consumption with age. (Untrained A, lean sedentary individuals; Untrained B, overweight sedentary individuals; Untrained A and B from Heath et al., (1981); •, average post-training $\dot{V}O_{2max}$ for subjects in current study)

compared to younger individuals (Reinhard, 1979; Cunningham, et al., 1985). In the current study, the average increase in $\dot{V}eT$ and $\dot{V}O_{2max}$ were similar. Therefore, the $\dot{V}eT \cdot \dot{V}O_2^{-1}$ was not altered with training. Because activities in daily living result in adaptations which attenuate the decline in the $\dot{V}eT$, Belman and Gaesser (1991) have suggested exercise training in the elderly is most likely to stimulate those physiological processes which result in an increase in $\dot{V}O_{2max}$ to a greater extent then those that result in an increase in $\dot{V}eT$. However, higher intensity longer duration exercise training may result in a greater increase in $\dot{V}eT \cdot \dot{V}O_2^{-1}$ than observed in this study. In younger individuals (mean age 25 years), Ready and Quinney (1982) observed a 19.4% increase in $\dot{V}eT \cdot \dot{V}O_2^{-1}$ after nine weeks of exercise training at ~ 80% $\dot{V}O_{2max}$. Poole and Gaesser (1985) compared the effects of continuous low (50% $\dot{V}O_{2max}$) or moderate (70 % $\dot{V}O_{2max}$) intensity exercise with that of an high intensity interval regimen (105% $\dot{V}O_{2max}$). After the training program, a 25% increase in $\dot{V}eT \cdot \dot{V}O_2^{-1}$ was reported for subjects assigned to the interval training program. No significant alteration in this variable was observed for the subjects assigned to the low or moderate continuous program. The 15% increase in $\dot{V}eT$ reported by Makrides and associates (1990) is similar to that observed in the current study and confirms that the elderly can adapt in a similar fashion to younger individuals after low to high intensity exercise training.

Despite no significant difference in absolute or relative $\dot{V}O_{2max}$ between the CT and AT subjects after training this is the first study to report that combined aerobic and strength training can improve $\dot{V}O_{2max}$ ($L \cdot min^{-1}$ or $ml \cdot kg^{-1} \cdot min^{-1}$) in the elderly. In younger subjects combined strength and endurance has been shown to increase cycle ergometer $\dot{V}O_{2max}$ (Hickson et al., 1980; Dudley and Djamil, 1985). The current study is unable to determine the precise role of either the strength or aerobic component in increasing $\dot{V}O_{2max}$ since there was not a group performing strength training alone. However, with the exception of the findings reported by Frontera and colleagues (1990) an exercise routine consisting solely of strength training does not increase cycle ergometer $\dot{V}O_{2max}$ in younger or older individuals (Hickson, et al., 1980; Hurley, et al., 1984; Dudley and Djamil, 1985; Panton, et al., 1990; Simpson, et al., 1993). Despite the above observations it is has been suggested that strength training in the elderly may increase the peripheral aspects of $\dot{V}O_{2max}$ in those individuals who have marked reductions in muscle mass and muscular strength.

Combined aerobic and resistance training resulted in a significant improvement in leg press muscular strength after eight weeks of exercise training. The magnitude of the increase in strength (18%) after training was significantly greater then that noted for the AT subjects. The enhanced lower extremity leg press muscular strength is similar to that observed in a group of elderly individuals (73 years of age) with chronic airflow obstruction after eight weeks of exercise training. However, other studies have demonstrated that higher intensity strength training (~ 70-90% 1 RM) performed three days per week for four months can increase leg press strength by 24% (Brown, et al., 1990; M^cCartney, et al., 1993). The discrepancy between the current study and the latter findings may be due to differences in training programs. Sale and colleagues (1990) assessed the effects of concurrent strength and endurance training in younger individuals (~ 21 years of age) who were randomly assigned to either a strength trained group (one limb performed strength training (S); contra lateral limb strength and endurance training [S + E]) or an endurance trained group (one limb performed endurance training (E); contra lateral limb performed endurance and strength training [E + S]). After 22 weeks of training all exercise groups (S, S+E, E, E + S) leg press 1 RM increased compared to pre-training. More importantly, the magnitude of the increase in strength after training was greater for the E + S compared to the E only group. The finding in the current study that an exercise regimen consisting predominantly of aerobic training with subsequent strength training can improve muscular strength to a greater extent then aerobic training alone is similar to that of Sale et al. (1990).

Despite a significant increase in knee extension and knee flexion maximal muscular strength in the CT subjects, the magnitude of this alteration was not appreciably different when compared to the AT subjects. The increase in muscular strength for the CT subjects is lower than a series of recent studies that have revealed that 8-12 weeks of lower extremity strength training at 80% 1 RM can result in a 107-174% and 227% improvement in leg extension and leg curl strength, respectively (Fiatarone, et al., 1990; Frontera, et al., 1990). The discrepancy between our results and that reported by the above investigators is most likely related to differences in training intensity. In the former studies lower extremity muscular strength was assessed weekly and the subjects trained at 80% of their new 1 RM whereas the CT subjects average training weight corresponded to ~ 60% of their pre-training 1 RM.

Moreover, the frail elderly subjects studied by Fiatarone, et al. (1990) were ~ 90 years of age and had remarkable reductions in muscle mass and strength. Therefore, it was not unexpected that a relative increase in strength of 200% would occur in this group. In younger subjects Hickson and associates (1980) reported that concurrent training resulted in a reduced ability to increase muscular strength without altering maximal aerobic power. The lower relative improvements in muscular strength in the CT subjects compared to the above studies may be due to an interference effect of performing combined aerobic and strength training.

Of particular interest in this study was the finding that the AT subjects had a significant improvement in knee flexion 1RM post training despite performing no strength movements. Cycle ergometer exercise primarily involves the quadricep, hamstring and gastrocnemius muscles. Therefore it was possible that this type of training may have resulted in an increase in hamstring strength. The finding that aerobic training can increase lower extremity strength in the elderly is not without precedent. Panton and associates (1990) observed a 5% increase in lower body strength in a group of aerobically trained subjects after 26 weeks of exercise training. Sale et al. (1990) further suggest that an exercise regimen consisting solely of endurance training can increase lower extremity strength. However, a limitation to the latter study is that the subjects trained each leg separately for either strength or endurance which may have resulted in the ipsilateral leg adapting to the stress imposed on the contra lateral leg.

A major limitation of this study was that there was not a control group or a group that strictly performed strength training. Therefore, it is unknown if combined aerobic and strength training effects the ability to adapt to strength training. Despite this uncertainty the CT subjects performed a significantly greater number of repetitions with their pre-training 1 RM compared to the AT group. Analysis of the average absolute endurance reveals that the CT subjects were able to perform twice as many repetitions compared to the AT subjects. Therefore, the CT subjects are able to perform high intensity muscular strength tasks without enduring local muscular fatigue compared to the AT subjects.

Distance covered during the six minute walk increased for all subjects with no difference observed for mode of training. Simpson and associates (1992) observed no significant increase in the distance covered in six minutes in subjects with chronic airflow obstruction despite an increase in maximal lower extremity muscular strength. The exact nature of the increase in walking distance is unclear because this type of training was not performed by the study subjects as part of the exercise training regimen. The increase in walking distance cannot be related to the increase in lower extremity strength because no significant difference was noted for the distance covered between the groups after exercise training. It may be possible that the subjects increased their walking patterns during the training program.

Chapter 5

Summary and Conclusions

5.1 Purpose

The purpose of this study was to determine if an exercise regimen consisting of combined aerobic and strength training would increase maximal oxygen consumption, lower extremity maximal muscular strength and distance walked during six minutes compared to an exercise regimen consisting solely of aerobic training.

5.2 Summary and conclusions

From the results the following conclusions are warranted:

1. Combined aerobic and strength training can increase maximal oxygen consumption however, the magnitude of the change is no greater then aerobic training performed alone.

2. Combined training can increase leg press strength and lower extremity leg press, knee extension and knee flexion absolute endurance to a greater extent then aerobic training alone.

3. Exercise prescription based on the $\dot{V}$eT is a safe and effective method of improving maximal oxygen consumption in the elderly.

4. Exercise interventions in the elderly should place emphasis on improving muscular strength, muscle mass, and cardiorespiratory fitness through a regimen consisting of combined aerobic and strength training.

5.3 Recommendations

The results of this study reinforce the observation that combined aerobic and strength training can increase cardiorespiratory fitness and maximal muscular strength. Moderate intensity exercise can increase the cardiovascular status of older individuals comparable to that observed for subjects 5-20 years younger.

The following recommendations are presented in hopes that further inquiry will be stimulated in this area.

1. Replication of this study with a larger number of subjects (n = 100) who will be randomly assigned into one of these groups: 1) a control group; 2) an aerobic trained group; 3) a strength trained group and, 4) an aerobic and strength trained group. This type of study will be able to determine if combined strength and aerobic training has an interference on strength or aerobic adaptations in the elderly.

2. Future studies should be undertaken to assess the effects of exercise training in males who have a normal resting cardiovascular status but have subsequent ischemia or silent ischemia during exercise testing.

3. To assess if combined training may be beneficial in special populations such as cogestive heart failure to increase muscular strength, muscle mass and cardiorespiratory fitness.

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APPENDIX A

ADVERTISEMENT FOR EXERCISE STUDY

WANTED !!

Males, 65-75 years old, currently not involved in regular physical activity (less than 3 times per week) to participate in an exercise study conducted by the University of Alberta: Departments of Cardiology & Physical Education

Each subject will receive a cardiovascular consultation consisting of a physical examination, electrocardiogram, and an exercise stress test.
Eligible subjects will be asked to participate in an 8 week exercise training program.
Exercise testing and training will be monitored by a Physician and/or a Registered Nurse.

For more information, please contact:

Dr. K. K. TEO
492 - 4037
or
Mr. M. Haykowsky R. N.
476 - 8409

APPENDIX B

CONSENT FORM FOR THE STUDY

CONSENT FORM

INFORMATION SHEET

TITLE OF THE RESEARCH PROJECT: Physiological Responses to Combined Aerobic and Resistance Training in Elderly Sedentary Male Subjects.

INVESTIGATORS: Dr. K.K. Teo, Dr. D.P. Humen, Dr. H.A. Quinney, Mr. M. Haykowsky R.N. B.P.E.

Increased age is associated with a decline in muscular strength and aerobic fitness. Recent studies have suggested that regular physical activity can counteract this decline. The Department of Physical Education and the Division of Cardiology at the University of Alberta Hospital are conducting a research study to find out which exercises are beneficial for elderly individuals. The aim of this research is to determine if certain exercises can improve leg strength, walking distance and aerobic fitness.

If you agree to participate you will have an equal chance of being assigned to a bicycle training group or a combined bicycle and weightlifting training group. You will be required to attend an exercise class approximately one hour long, three times per week, for eight weeks.

At the beginning of the study you will undergo a physical examination and a bicycle exercise test. If you are free from cardiovascular abnormalities you will be asked to complete a second similar exercise test. You will also perform a six minute walk test and lower extremity muscular strength assessments. The latter two tests will be repeated one week after the bicycle test. If a discrepancy exists between any of the two tests a third assessment may be undertaken. All tests will be repeated at the end of the study.

Throughout the bicycle exercise test your heart rate and rhythm as well as the amount of oxygen you use will be monitored. During this test a special mouthpiece and a noseclip will be used. This may cause slight discomfort and a feeling of confinement but involve no risks. After the bicycle exercise test and lower extremity maximal muscular strength testing you may feel some discomfort in your legs.

The exercise tests that you will perform are generally very safe. However, data from individuals with or without heart disease indicates that the likelihood of dying suddenly during an exercise test is 1 in 20,000 exercise tests.

The potential benefits that you may encounter from this study consist of an improvement in lower leg strength and aerobic fitness. All exercise training and testing sessions will be monitored by a Physician and/or Nurse.

CONSENT

TITLE OF THE RESEARCH PROJECT: Physiological Responses to Combined Aerobic and Resistance Training in Elderly Sedentary Male Subjects.

INVESTIGATORS: Dr. K.K. Teo, Dr. D.P. Humen, Dr. H.A. Quinney, Mr. M Haykowsky R.N. B.P.E.

I acknowledge that the research procedures described on the Information Sheet (attached) and of which I have a copy have been explained to me, and that any questions that I have asked have been answered to my satisfaction. In addition, I know that I may contact the persons designated on this form, if I have further questions either now or in the future. I understand the possible benefits of joining the research study, as well as the possible risks and discomforts. I have been assured that personal records relating to the study will be kept confidential and that my name will not be published or presented at conferences. I understand that if any knowledge gained from the study is forthcoming that could influence my decision to continue in this study, I will be promptly informed. I understand that I can withdraw from the study at any time without effecting my medical care.

____
(Name)

The persons who may be contacted about the research are:

Dr. K.K. Teo:
Telephone No. 492-4037

Dr. D.P. Humen:
Telephone No. 492-1576

Mr. M. Haykowsky:
Telephone No. 476-0409

____
(Signature of subject)

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(Name)

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(Signature of Witness)

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(Date)

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(Signature of Investigator or designee)

APPENDIX C
PRE-TRAINING PHYSICAL EXAMINATION

PHYSIOLOGICAL RESPONSES TO COMBINED AEROBIC AND STRENGTH TRAINING IN SEDENTARY ELDERLY MALES
PRE-TRAINING VISIT

MEDICAL HISTORY: WRITE ALL CONDIDTIONS, BY SYSTEMS, WHICH ARE PRESENT OR ONGOING AT THE SCREENING VISIT.

HEIGHT: **WEIGHT:**
CNS:

CARDIOVASCULAR:
BP: **HR:** **RHYTHM:**

S_1: S_2: S_3: S_4:

RESPIRATORY:
LUNG SOUNDS:
CLEAR: **SOB:**
CRACKLES: **PND:**
WHEEZES: **COUGH:**

GI:

GU:

MUSCULO-SKELETAL:

OTHERS:

MEDICATIONS:

APPENDIX D
EXERCISE TRAINING PROTOCOL

AEROBIC TRAINING

Week	Session	Duration of aerobic phase
1	1-3	15.0 minutes
2	4-6	17.5 minutes
3	7-9	20.0 minutes
4	10-12	22.5 minutes
5	13-15	25.0 minutes
6	16-18	27.5 minutes
7	19-21	30.0 minutes
8	21-24	32.5 minutes

STRENGTH TRAINING

Week	Session	Percent 1 RM	Sets	Reps
1	1-3	40	3	15
2	4-6	45	3	15
3	7-9	50	3	15
4	10-12	55	3	15
5	13-15	60	3	10
6	16-18	65	3	10
7	19-21	70	3	10
8	21-24	75	3	10

APPENDIX E

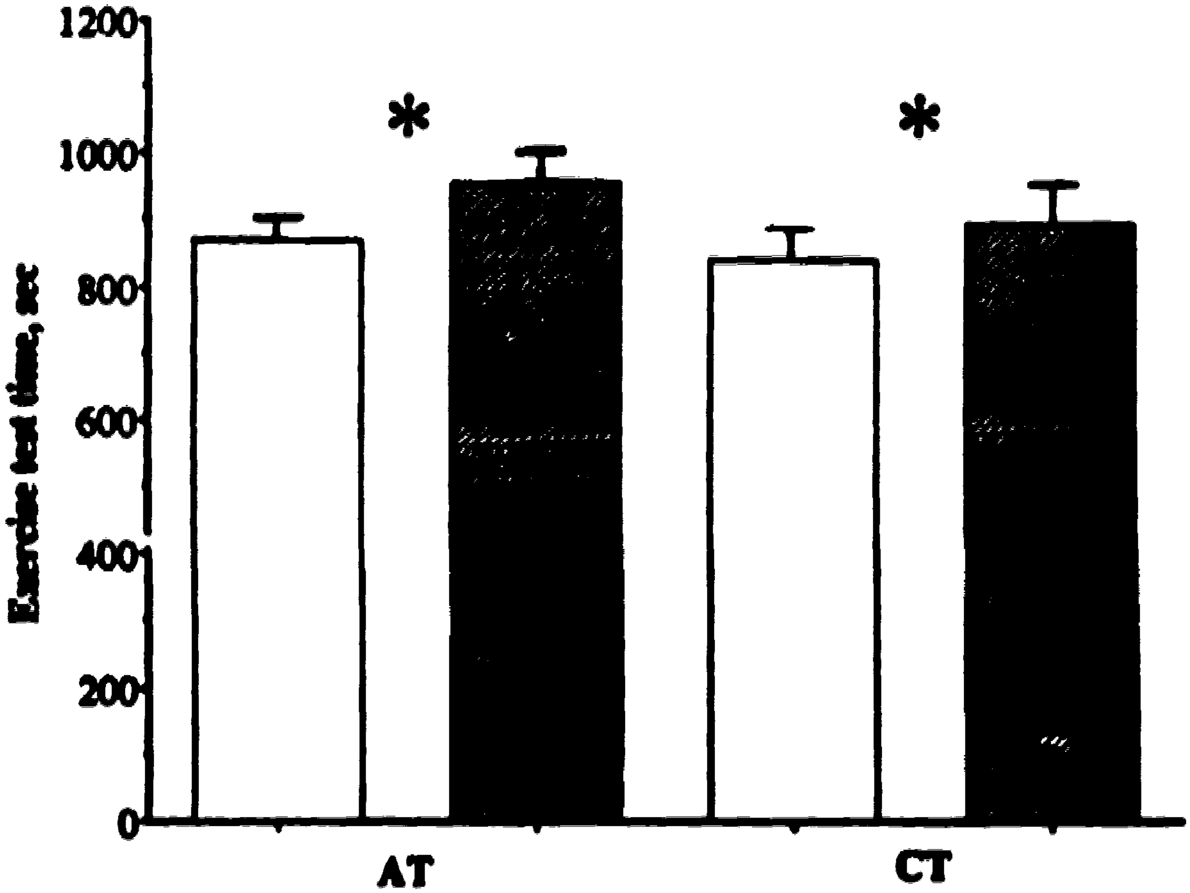
PRE TEST RELIABILITY

INTER CLASS CORRELATION COEFFICIENT FOR PRE TEST VARIABLES

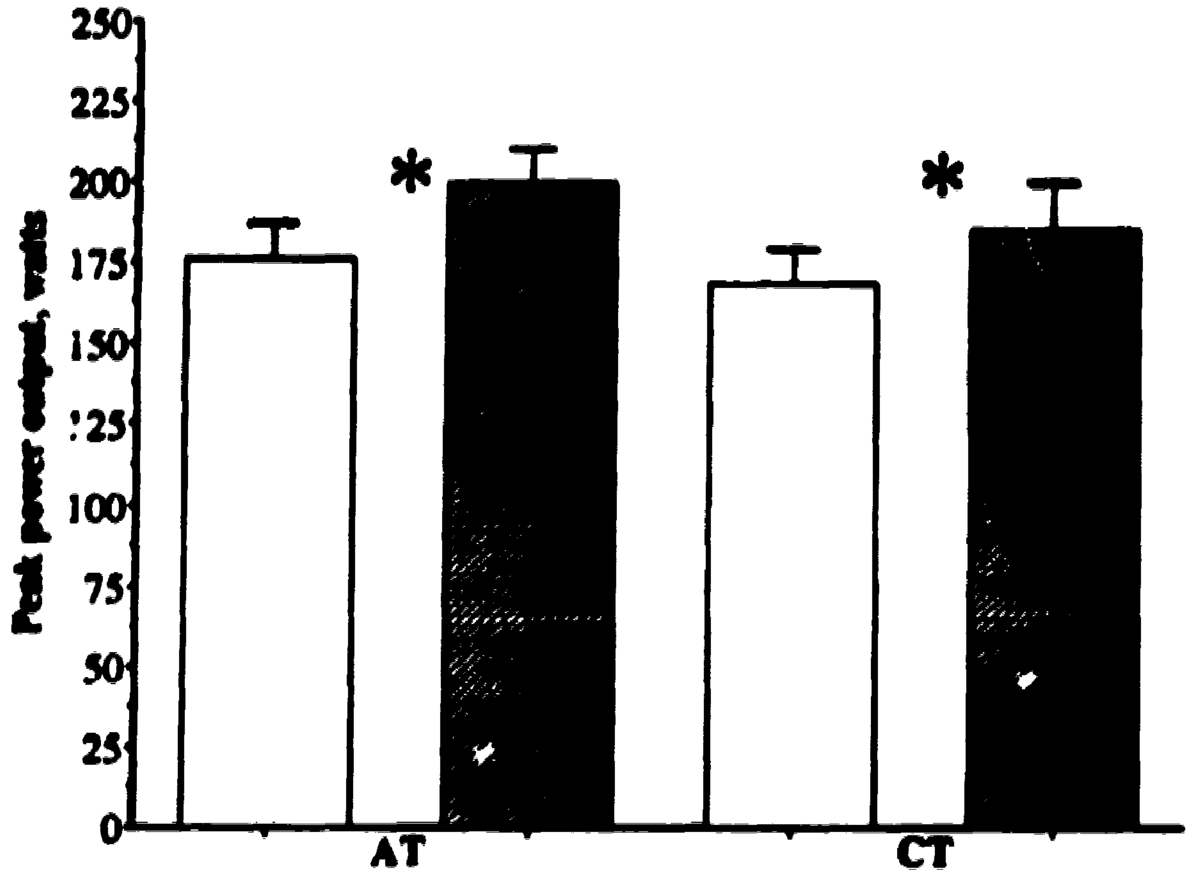
VARIABLE	INTER CLASS CORRELATION
$\dot{V}O_{2max}$ ($L \cdot min^{-1}$)	.82
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	.89
Test time	.87
Peak power output	.84
Leg press 1 RM	.86
Knee extension 1 RM	.79
Knee flexion	.93
Six minute walk test	.94

APPENDIX F

EXERCISE TEST DURATION AND PEAK POWER OUTPUT AFTER EIGHT WEEKS OF EXERCISE TRAINING



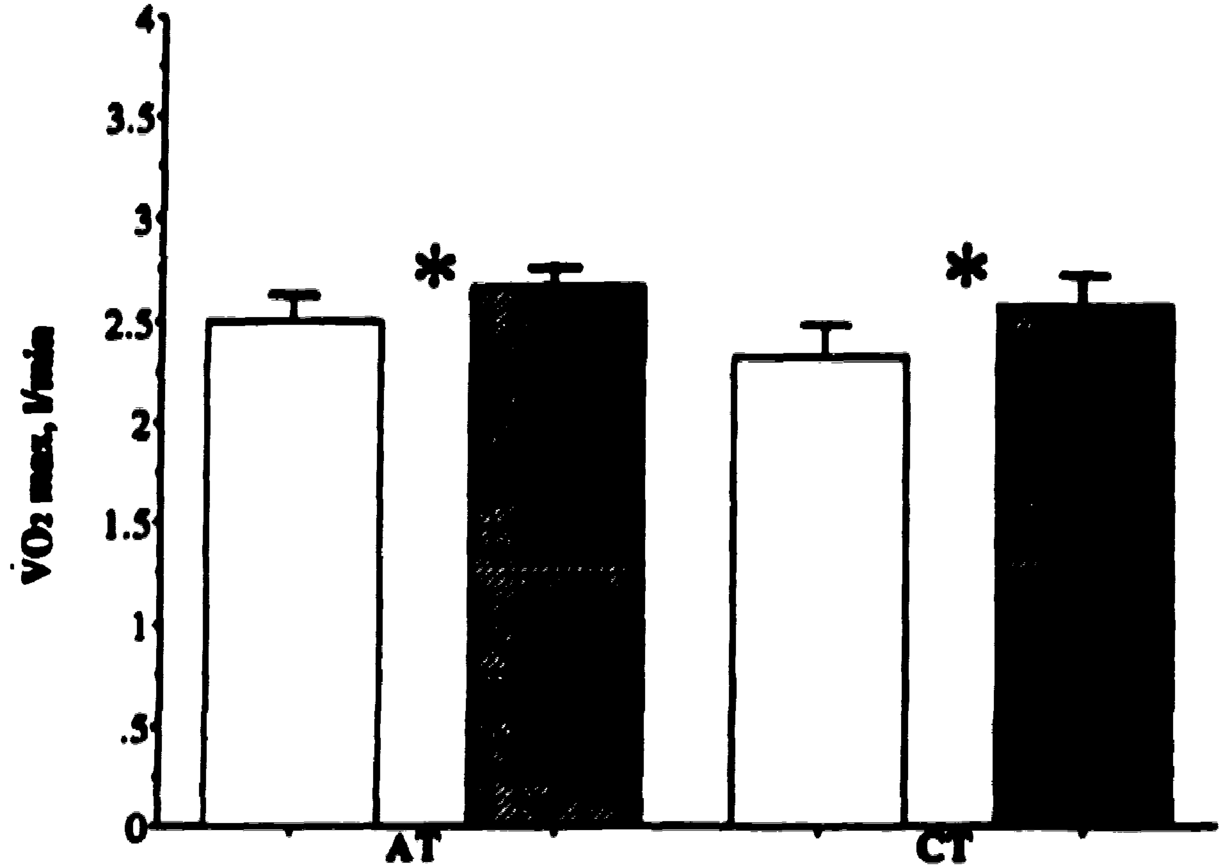
Exercise test duration before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.



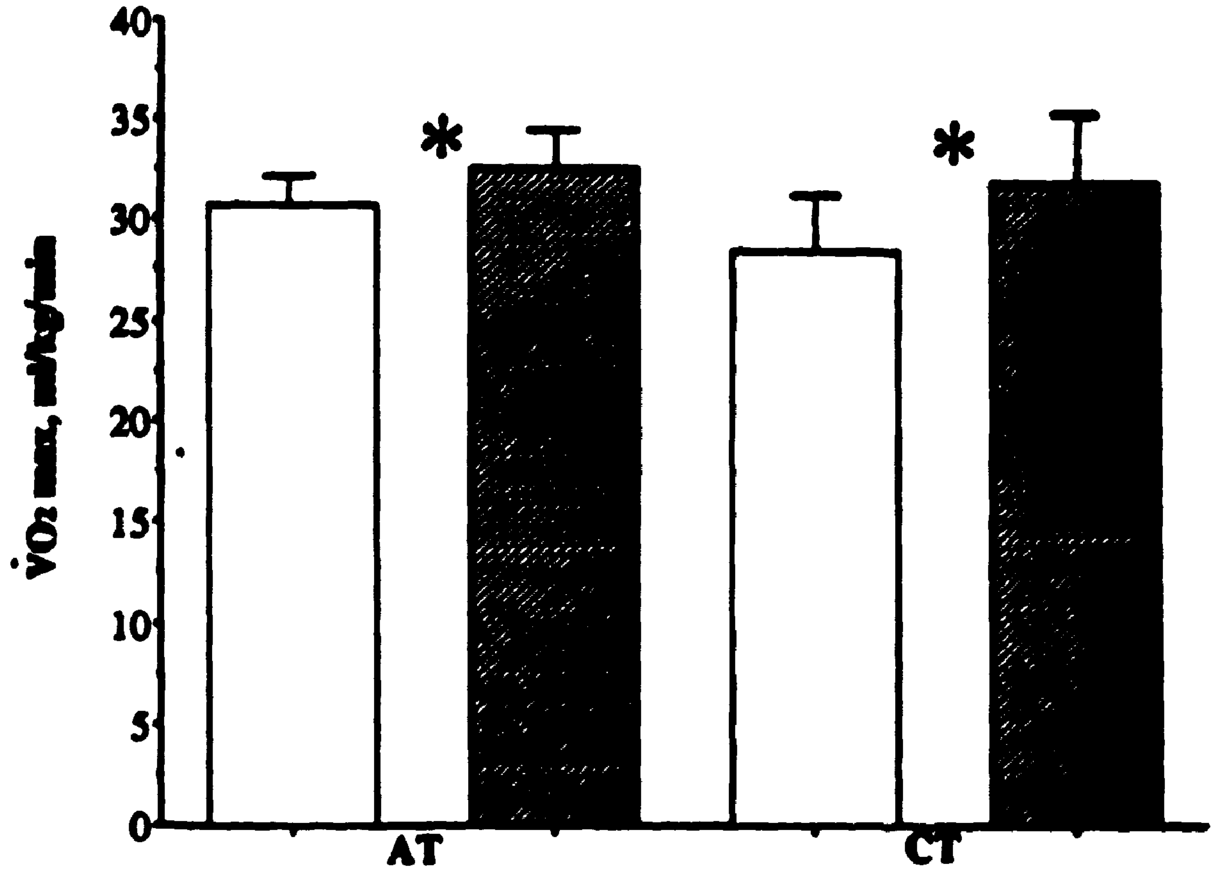
Peak power output before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.

APPENDIX G

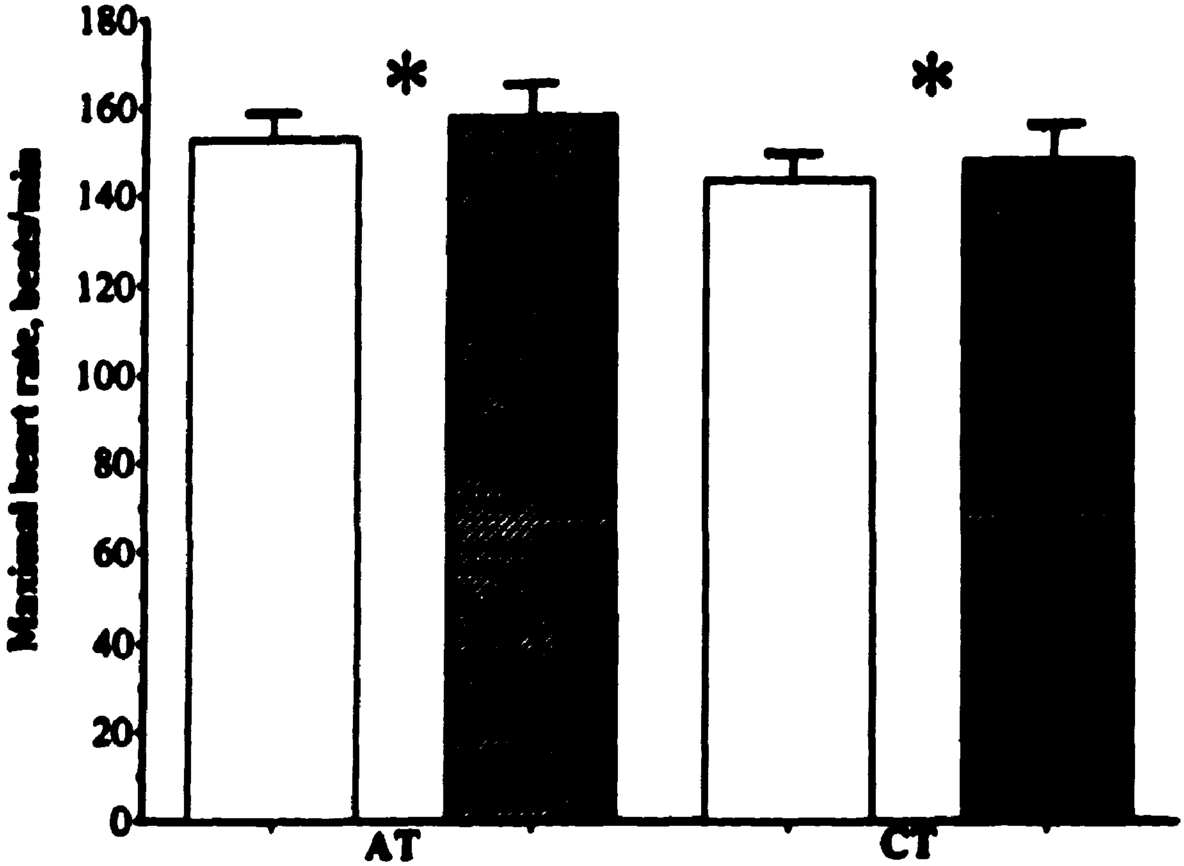
EFFECTS OF EXERCISE TRAINING ON MAXIMAL CARDIORESPIRATORY MEASURES DURING THE SYMPTOM LIMITED GRADED EXERCISE TEST



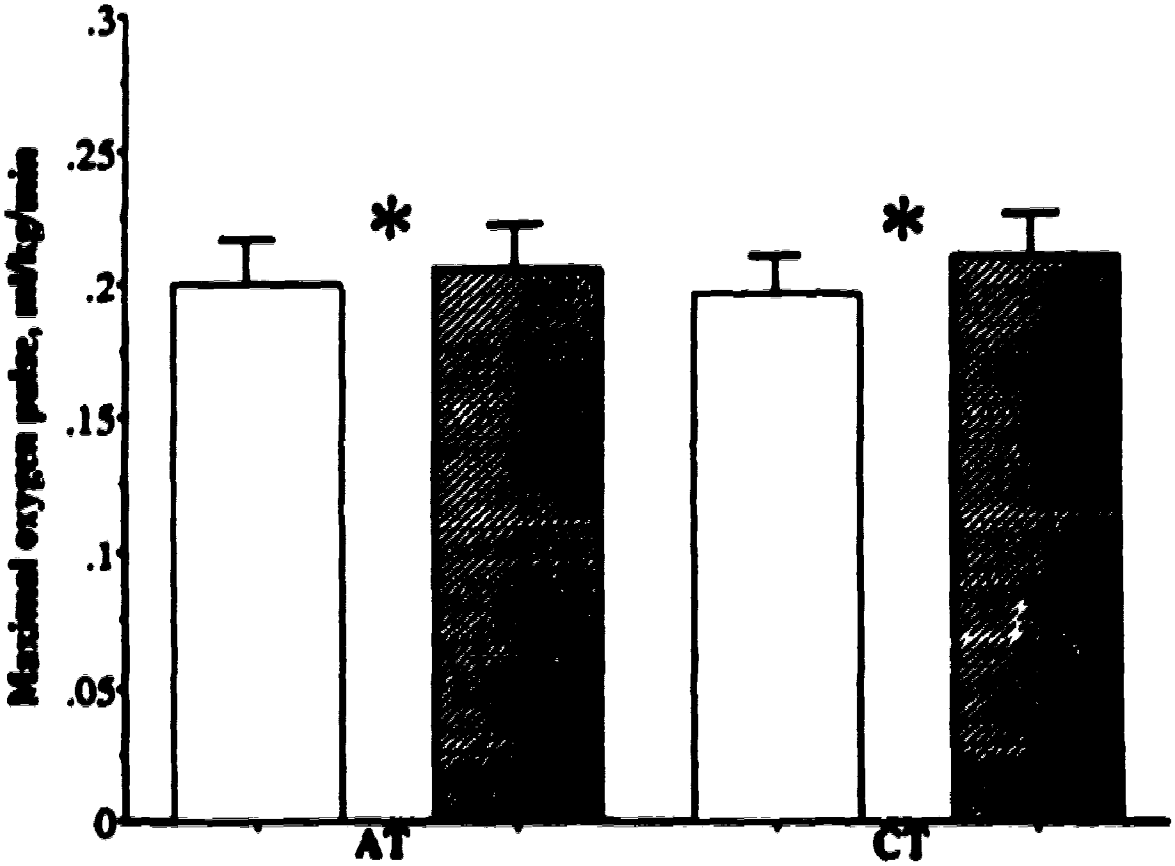
Maximum aerobic power before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.



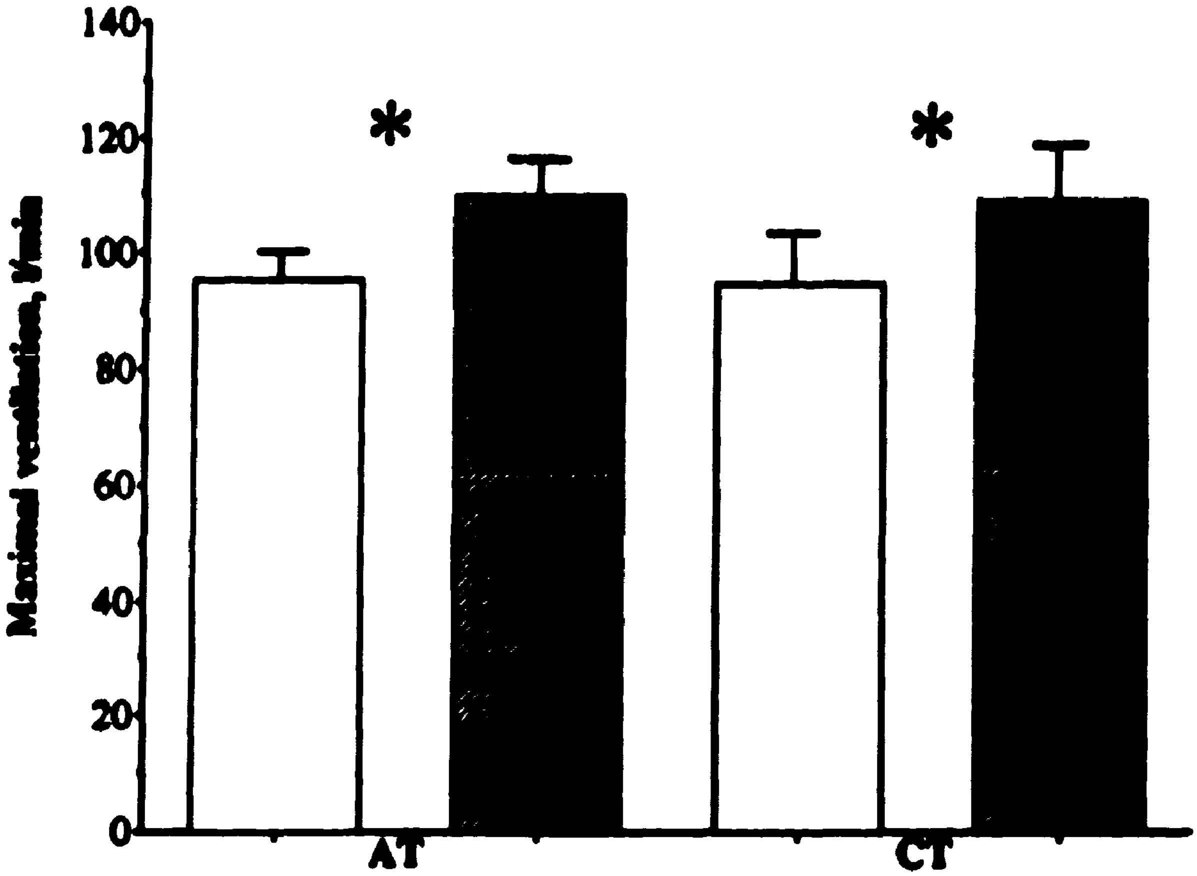
Maximum aerobic power before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.



Maximal heart rate before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.



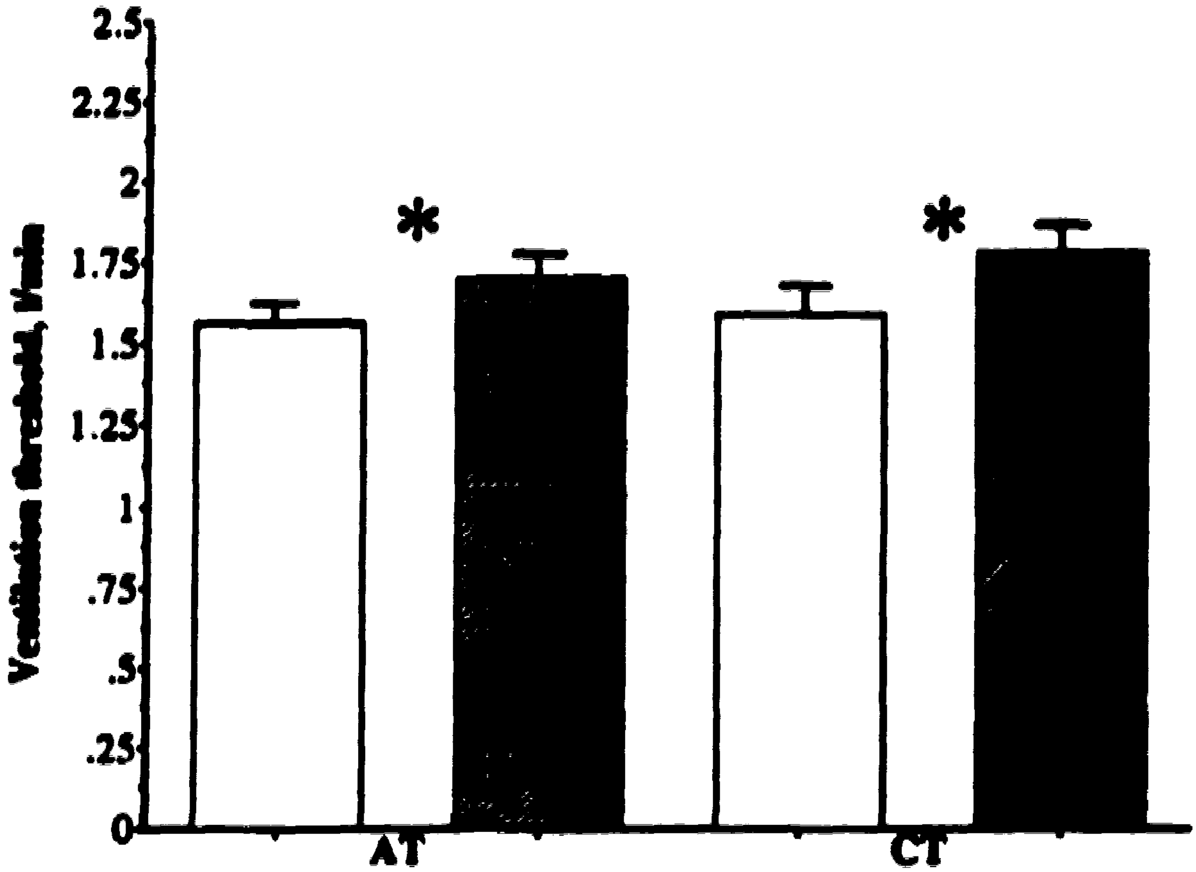
Maximal oxygen pulse before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.



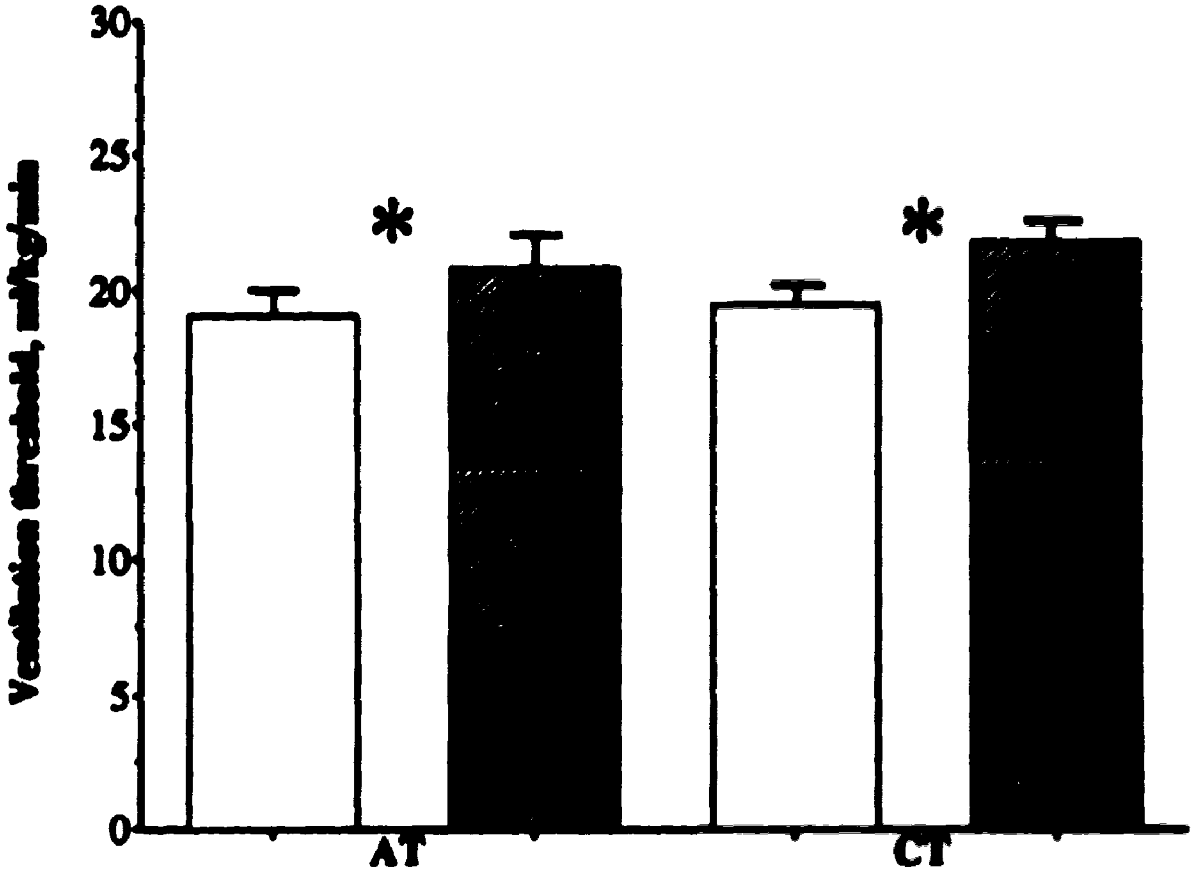
Maximal ventilation before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.

APPENDIX H

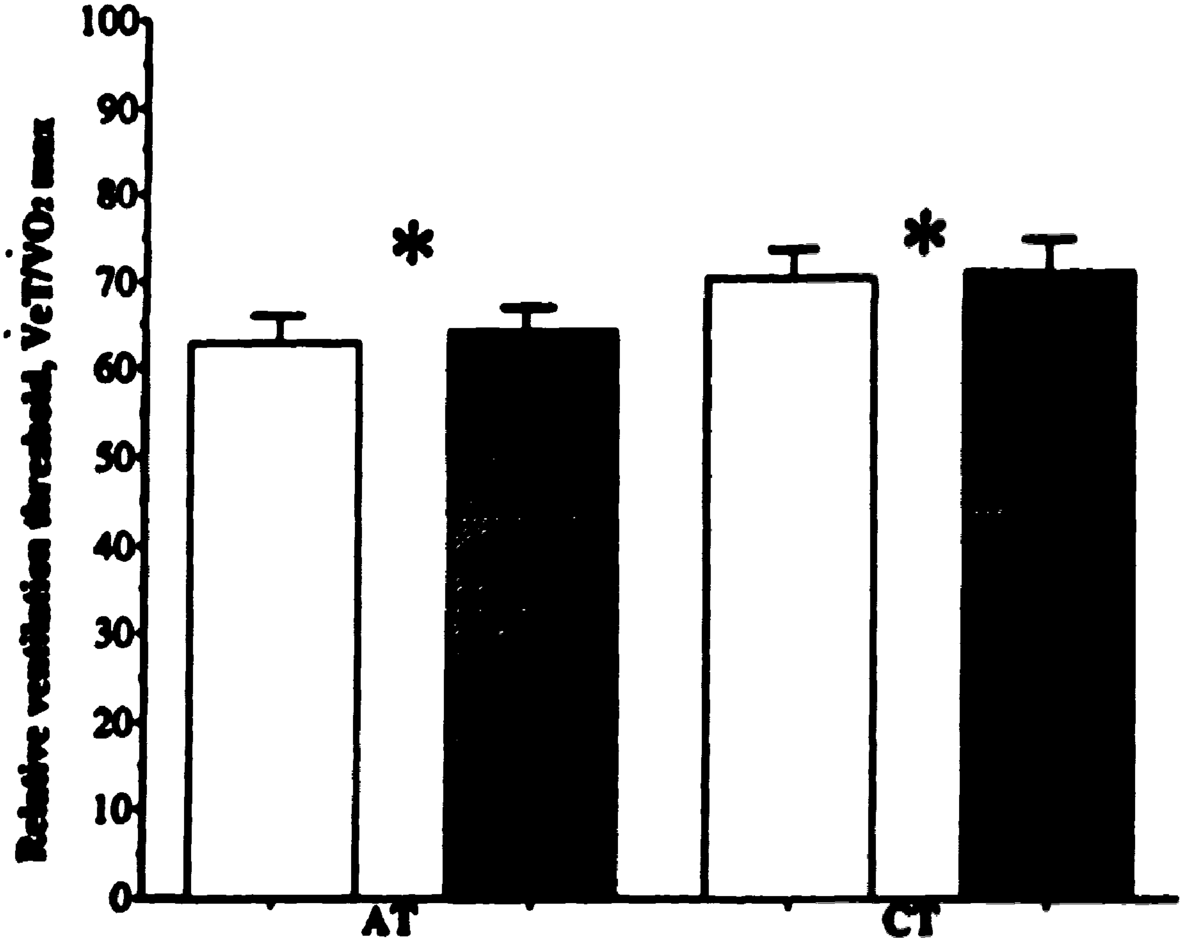
EFFECTS OF EXERCISE TRAINING ON THE ABSOLUTE AND RELATIVE VENTILATION THRESHOLD



Ventilation threshold before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.



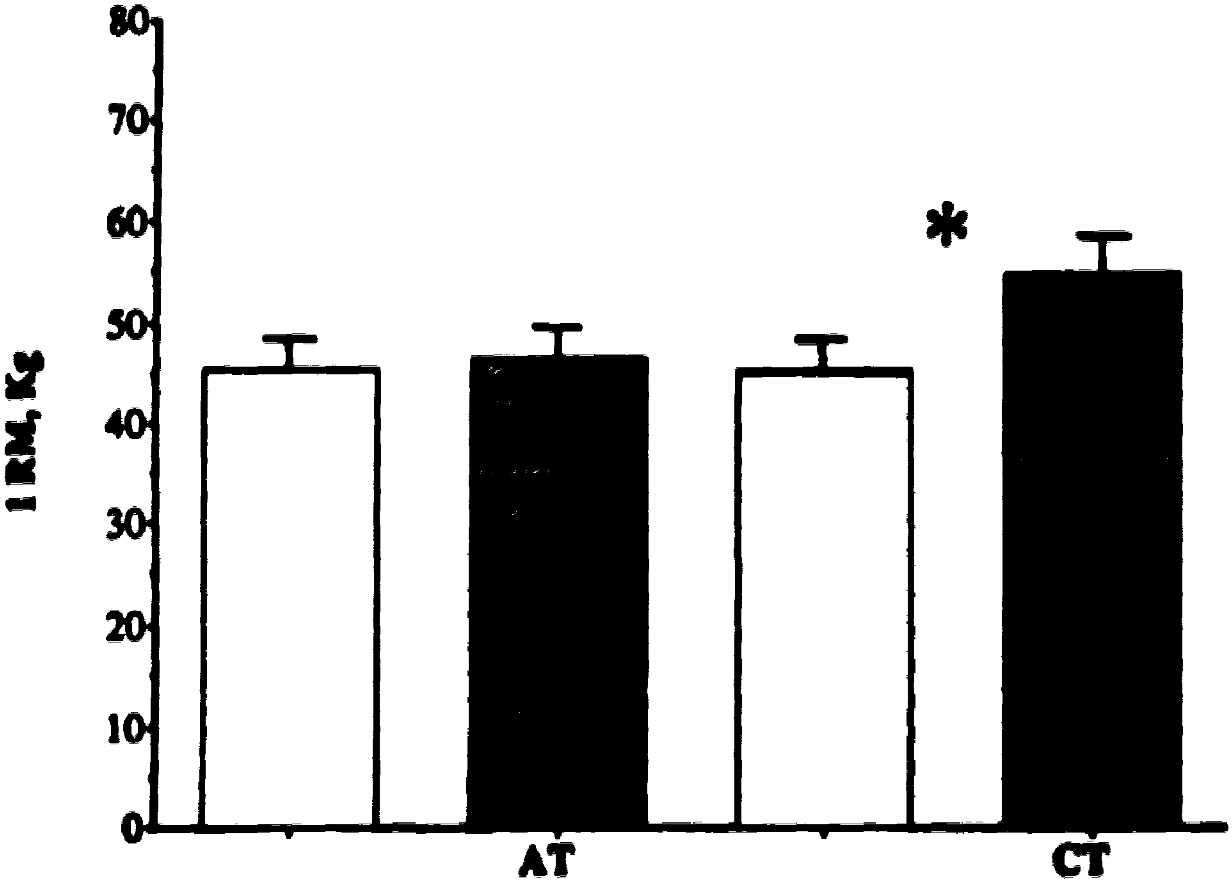
Ventilation threshold before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.



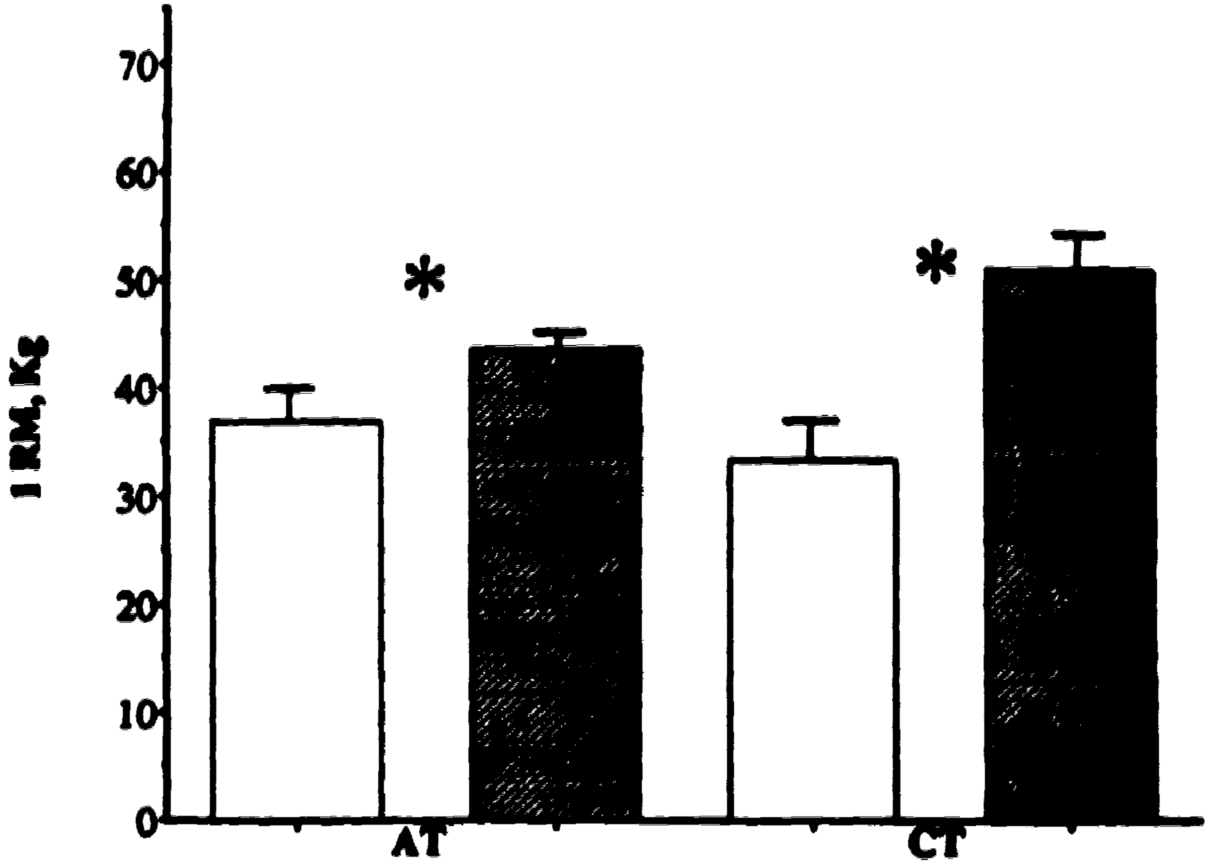
Relative ventilation threshold before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.

APPENDIX 1

EFFECTS OF EXERCISE TRAINING ON KNEE EXTENSOR AND FLEXOR MAXIMAL MUSCULAR STRENGTH



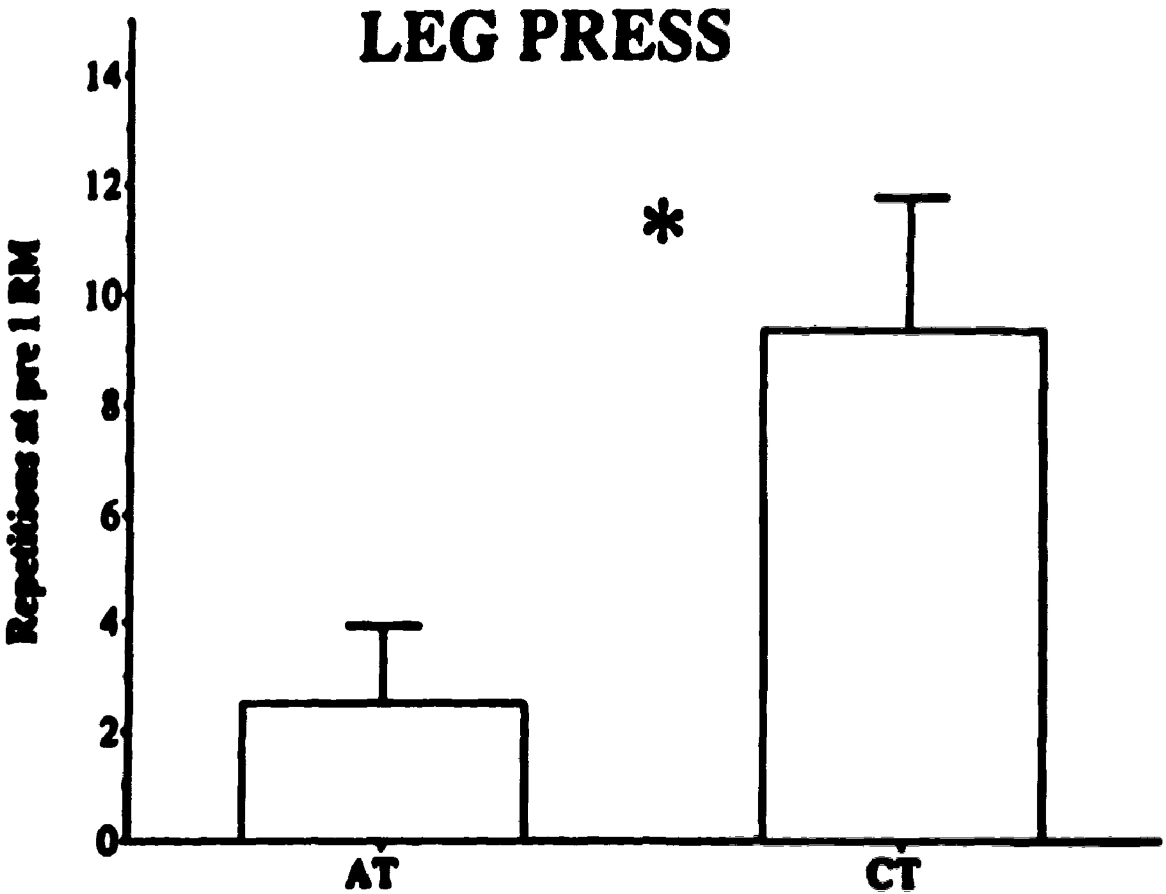
Knee extension maximal muscular strength before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.



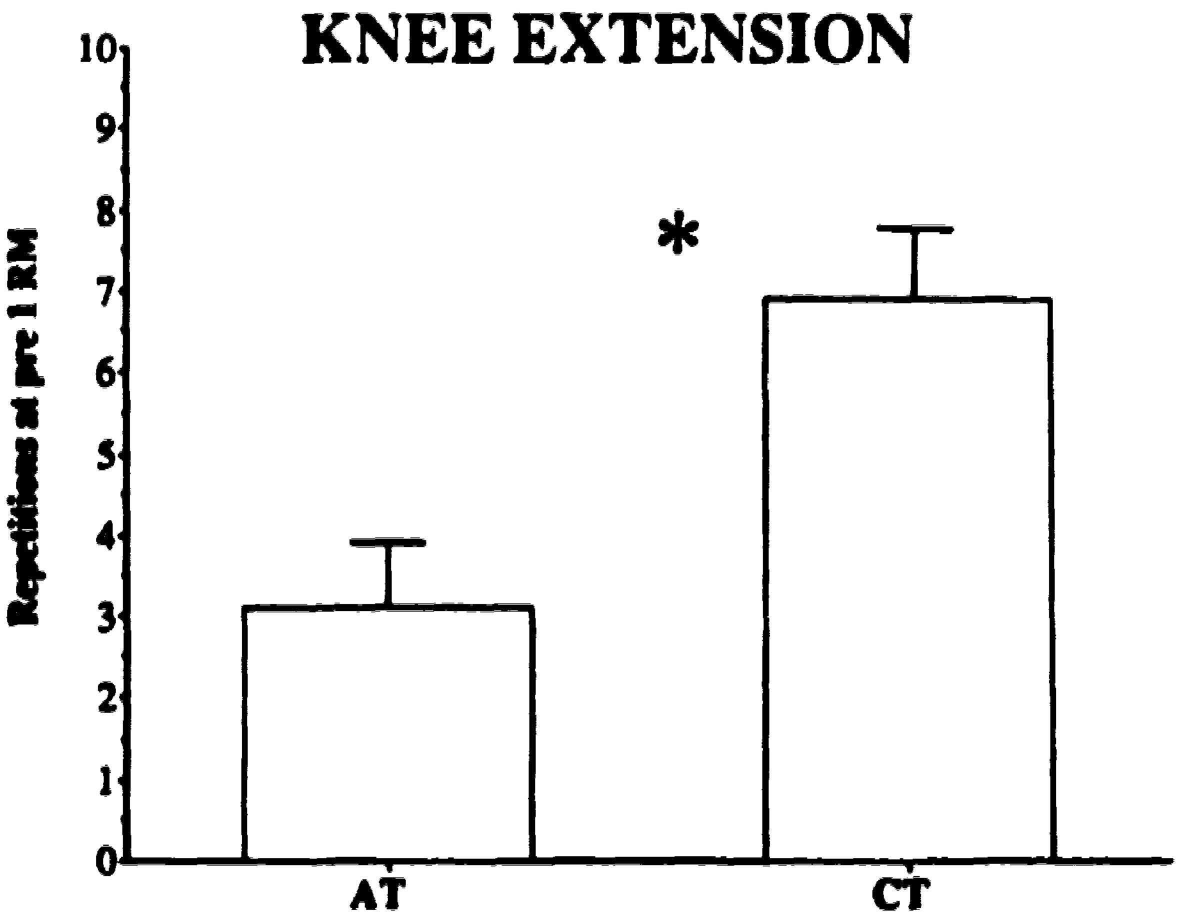
Knee flexion maximal muscular strength before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.

APPENDIX J

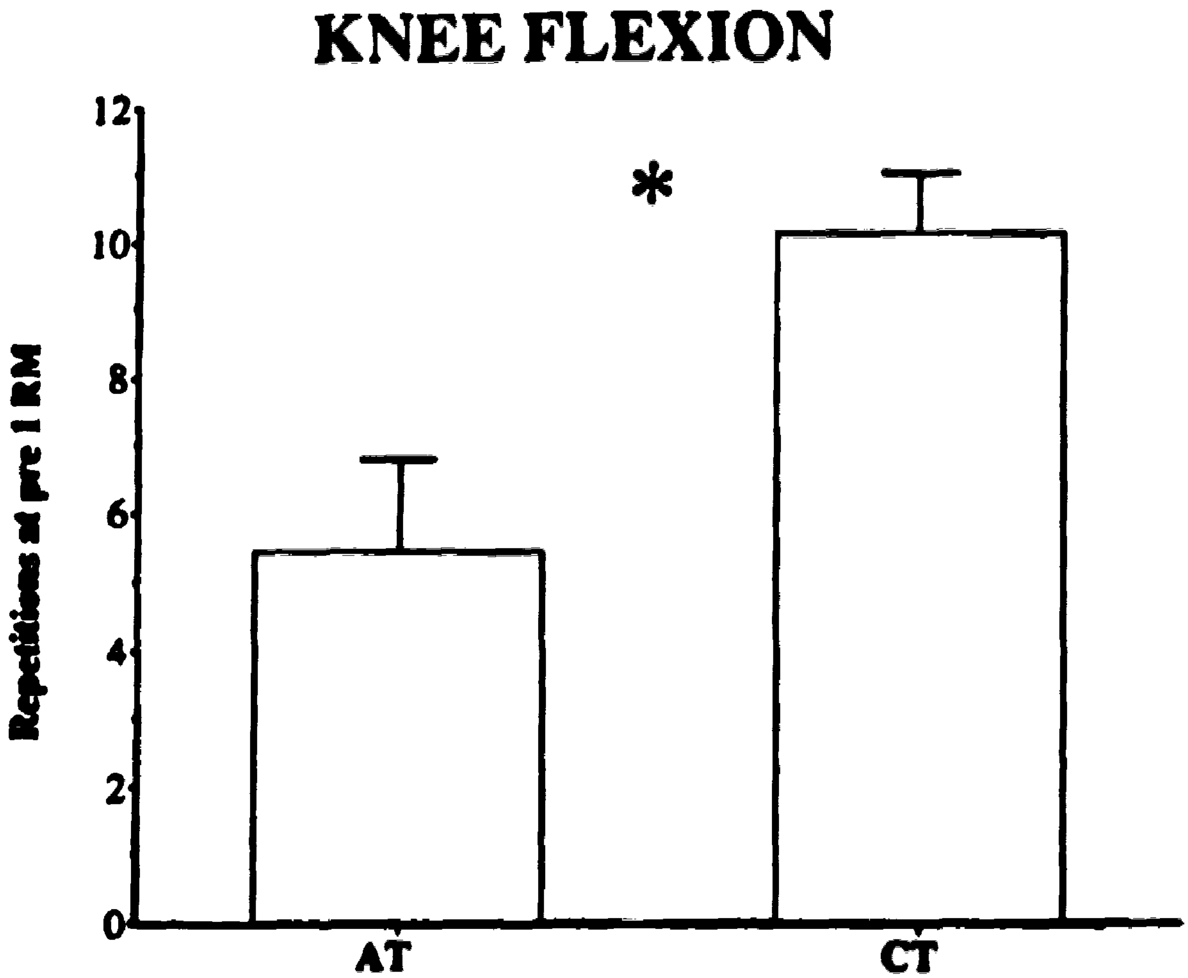
EFFECTS OF EXERCISE TRAINING ON LEG PRESS, LEG EXTENSION AND FLEXION ABSOLUTE ENDURANCE



Repetitions done, after training, with the heaviest weight that could be lifted for 1 repetition before training in the AT and CT groups. Values are means ± SE. Main effect CT> AT: * $P < 0.05$.



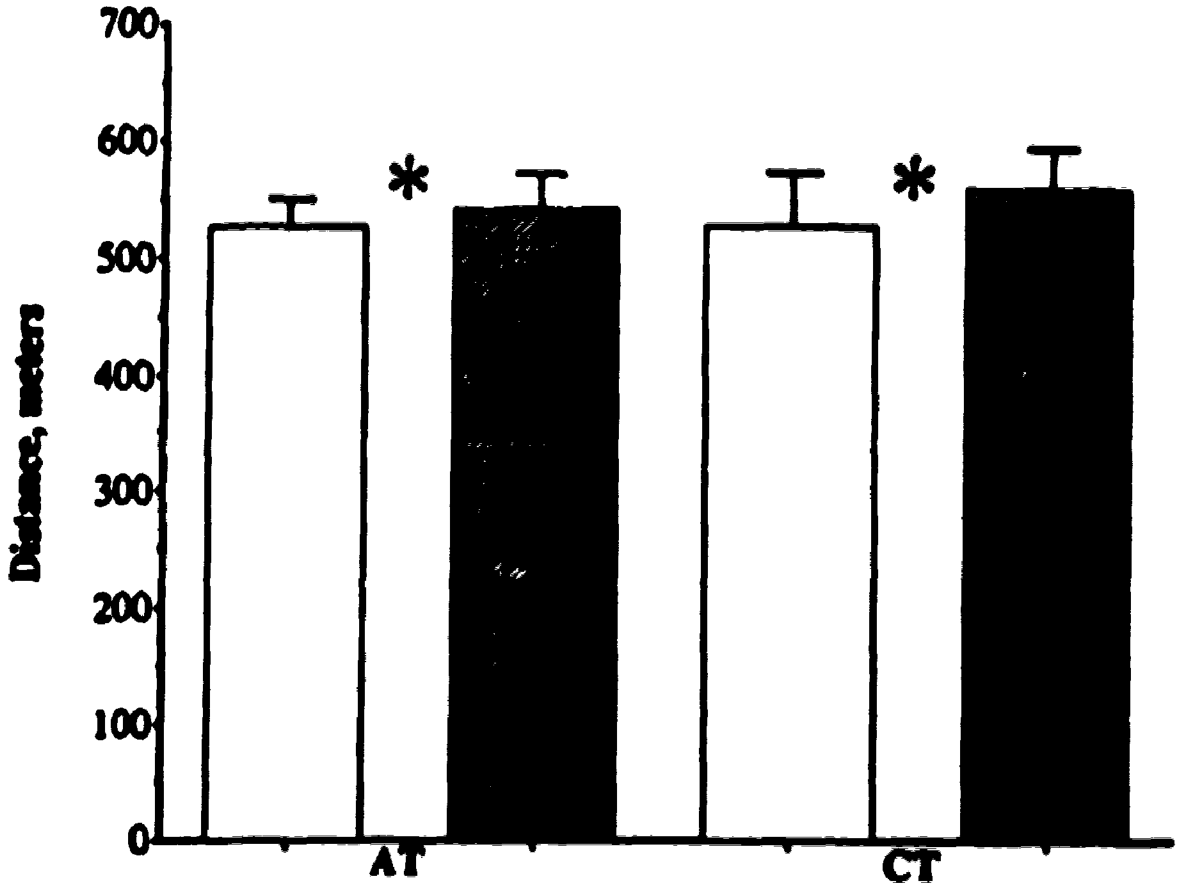
Repetitions done, after training, with the heaviest weight that could be lifted for 1 repetition before training in the AT and CT groups. Values are means ± SE. Main effect CT > AT: * $P < 0.05$.



Repetitions done, after training, with the heaviest weight that could be lifted for 1 repetition before training in the AT and CT groups. Values are means ± SE. Main effect CT > AT: * $P < 0.05$.

APPENDIX K

EFFECT OF EXERCISE TRAINING ON DISTANCE COVERED DURING THE SIX MINUTE WALK TEST



Maximum distance walked in six minutes before and after eight weeks of aerobic (AT) or combined (CT) exercise training. Values are means ± SE. Main effect before (open bars) vs. after (hatched bars) training: * $P < 0.05$.