CIRCULATORY RESPONSES TO WEIGHT TRAINING

IN CARDIAC PATIENTS

WEIGHTLIFTING TRAINING IN CARDIAC PATIENTS: EFFECT ON CIRCULATORY RESPONSES DURING LIFTING AND IN STRENGTH RELATED ACTIVITIES OF DAILY LIVING

By

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A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Master of Science

McMaster University

August 1991

MASTER OF SCIENCE (1991) McMASTER UNIVERSITY
(Human Biodynamics) Hamilton, Ontario

TITLE: Weightlifting Training in Cardiac Patients:
Effect on Circulatory Responses During Lifting
and in Strength Related Activities of Daily Living

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NUMBER OF PAGES: xii, 169

This thesis is dedicated to ...

my mother and father, June Marie and Michael Wiecek
for their unlimited encouragement and enthusiastic support;

my sisters, Lynda, Irene, Helen, and Susie
for their guidance and inspiration;

and finally, Gerry Forbes
for his continual support and motivation.

Acknowledgements

I would like to extend my appreciation to my advisor, Dr. Neil McCartney, and the members of my supervisory committee, Drs. Duncan MacDougall, Bob McKelvie, and Digby Sale.

I would also like to thank Drs. Tim Lee and Digby Elliott for their statistical advice, Joan Martin for her assistance in the laboratory, and all of the subjects who participated in this research study.

ABSTRACT

The purpose of this thesis investigation was to evaluate the effects of combined aerobic and weightlifting training on the circulatory responses of patients with coronary artery disease (CAD) during formal lifting, and during strength related activities of daily living.

Seven subjects ($\bar{x}$ age: 54 years) successfully completed 20 sessions of training within 12 weeks. The aerobic training regimen consisted of a 5-10 minute warm up, walking, arm buoys, and arm- and leg- cycling at an intensity equivalent to approximately 70% of functional capacity. The weightlifting regimen consisted of single-arm curl (SAC), and single-leg press (SLP) exercises performed by both limbs, in addition to modified trunk curls.

Before and after training, intra-brachial artery pressure was measured continuously during: 10 repetitions of the seated SAC exercise at 70% of the subject's one repetition maximum (1 RM), 12 repetitions of the SLP and double-leg press (DLP) exercises at 80% of 1 RM, isometric handgrip at 50% of maximal voluntary contraction strength, 10 flights of stair climbing at a cadence of 60 steps/minute, and 10 minutes of horizontal treadmill walking at 3.5 mph.

Training increased the SAC, SLP, and DLP 1 RM strength by 98% (15 vs 30 kg; $p < 0.016$), 23% (99 vs 122 kg; $p < 0.002$), and 27% (165 vs 210 kg; $p < 0.001$) respectively.

The mean peak systolic, diastolic, and mean arterial pressures, heart rate and rate pressure product were attenuated in all 3 weightlifting exercises when subjects lifted the same absolute load (70% of the pre-training 1 RM for the SAC exercise, and 80% of the pre-training 1 RM for the SLP and DLP exercises) after training. When subjects lifted the same relative load after training, all circulatory responses increased.

The average peak heart rate and arterial pressure responses were reduced during 10 minutes of horizontal treadmill walking after training. In contrast, there was little or no reduction in any of the measured parameters during stair climbing.

It is concluded that weightlifting training in CAD patients results in an attenuation of the heart rate and arterial blood pressure responses during repeated lifting with identical absolute loads, and there may be a modest transfer of this effect to certain activities of daily living involving the trained muscles.

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1.1 Introduction

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in Canada, and has been since 1920. It causes more hospitalizations than any other disease, and direct hospital costs to Canadians have been estimated to be in excess of 3 billion dollars each year. In 1988, nearly 80,000 Canadians died from CVD (Statistics Canada, 1991).

A number of risk factors have been found to increase an individual's chance of developing coronary artery disease (CAD), the most common form of CVD. Some of these, such as age, gender, and genetic susceptibility, can not be changed. However, other factors such as hypertension, elevated serum cholesterol, smoking, obesity and physical inactivity are related to an individual's lifestyle and may be modified.

Many treatment strategies are currently being utilized to reduce or eliminate the modifiable risk factors for CAD. These include dietary alterations and pharmacologic interventions aimed at decreasing blood pressure and serum cholesterol levels, the cessation of smoking and regular physical exercise.

1.2 The Evolution of Cardiac Exercise Rehabilitation

Treatment strategies for patients with CAD have changed drastically over the years. During the period 1920 - 1950, bed rest was central to cardiac care. Lewis (1933) stated that every effort should be made by cardiac patients to avoid physical activity, and Mallory et al. (1939) found that following an acute myocardial infarction, 3-4 weeks were required for the major portion of the necrotic myocardium to be removed and replaced by scar tissue. Therefore, 6 weeks or more (twice the healing time) of rigid, restrictive bed rest was prescribed for the patient. The prognosis of cardiac patients was considered to be poor, and it was assumed that prolonged morbidity and mortality were inevitable (Hellerstein, 1986).

It wasn't until the 1940's that some of the ill effects of bed rest were recognized (Dock, 1944; Harrison, 1944; Taylor et al., 1949).
Levine and Lown (1951) later developed the "chair treatment" in order to encourage early mobilization of patients after an acute myocardial infarction. Approximately 2 decades later, Saltin et al. (1968), demonstrated that only 2-3 weeks of bed rest resulted in deterioration of cardiovascular function. These findings led physicians to question the traditional patient management of bed rest and immobilization following a myocardial infarction, and therapeutic exercise programmes were developed to prevent or reduce deconditioning, thromboembolism and emotional invalidism (Wenger et al., 1970).

In the 1960's, several investigators demonstrated that physical training of cardiac patients produces beneficial effects (Hellerstein et al., 1965;

Barry et al., 1966; Varnauskas et al., 1966; Katz, 1967; Clausen et al., 1969) and since then, exercise rehabilitation has become an accepted form of therapy for patients with CAD.

More recently, Oldridge et al. (1988) performed an analysis on randomized trials of cardiac rehabilitation after myocardial infarction, and found that the risk of cardiovascular mortality may be reduced by as much as 25% following exercise rehabilitation. In addition, O'Connor et al. (1989) conducted an overview of selected randomized trials of exercise rehabilitation after myocardial infarction and demonstrated a 20% reduction in the risk of mortality that persists for at least 3 years. Morbidity, on the other hand, was not found to be significantly different (Oldridge et al., 1988; O'Connor et al., 1989).

1.3 Traditional Approaches to Cardiac Exercise Rehabilitation

A few days after an uncomplicated myocardial infarction, exercise rehabilitation begins in the hospital (Phase 1) with self-care activities and selected arm and leg exercises designed to maintain muscle tone and joint mobility. In addition to this, the patient walks progressively longer distances each day. The primary goal of the programme is to offset the detrimental physiologic and psychologic effects of bed rest (American College of Sports Medicine, 1986; Brannon et al., 1988).

Phase 2 of cardiac exercise rehabilitation is usually initiated immediately following hospital discharge and is conducted 3x/week for 2-3 months. Ideally, patients exercise in a facility that offers continuous ECG monitoring, emergency equipment, and medical supervision. The goal of Phase 2 rehabilitation is to provide exercises that prepare the patient to return to work and resume regular activities of daily living (American College of Sports Medicine, 1986; Brannon et al., 1988).

Phase 3 of exercise rehabilitation generally begins 6-12 weeks after hospital discharge and lasts between 6 and 12 months. The programme is conducted in a community facility such as the Y.M.C.A., Y.W.C.A., or a university. The primary goal at this stage is to improve the patient's functional capacity and maintain it at a level that allows activities of daily living to be carried out with relative ease (American College of Sports Medicine, 1986; Brannon et al., 1988).

Traditionally, Phase 3 cardiac exercise rehabilitation involves large muscle groups in relatively low intensity aerobic activities, such as walking and stationary cycling, designed to improve the oxygen transport system.

1.4 Effects of Aerobic Training on Circulatory Responses in CAD Patients

The circulatory responses to aerobic training in CAD patients have been well documented (Clausen, 1976; Amsterdam et al., 1981; Ehsani et al., 1982; Hagberg et al., 1983).

1.4.1 Circulatory Responses at Rest

The major circulatory adaptations at rest are a reduction in heart rate, and either no change or a slight reduction in stroke volume, cardiac output and arterial pressure (Detry et al., 1971; Clausen, 1976).

1.4.2 Circulatory Responses During Exercise at Submaximal Workloads

The most pronounced effects of aerobic training in CAD patients have been demonstrated during submaximal exercise with the trained limbs. Arterial pressure, heart rate and cardiac output decrease, while stroke volume increases slightly or does not change. The arteriovenous oxygen difference (AV-O_2d) in the working muscles increases due to local adaptations in the trained muscles, and blood flow to this region is reduced. In contrast, the reduction in blood flow to abdominal viscera and non-working muscles during submaximal exercise is less pronounced at a given $\dot{V}O_2$ following training. The mechanism for this is thought to be a decrease in the sympathetic vasoconstrictive tone in the non-exercising tissues, and therefore, in total peripheral resistance (Clausen, 1976; Ehsani et al., 1982; Hagberg et al., 1983).

The end result of these circulatory adaptations is an increase in exercise tolerance, and a reduction in myocardial oxygen demand ($M\dot{V}O_2$) with a concomitant increase in the intensity of exercise needed to precipitate angina pectoris.

1.4.3 Circulatory Responses During Exercise at Maximal Workloads

Increases in maximal oxygen uptake ($\dot{V}O_2$ max) ranging from 16-56% have been reported in patients with CAD following aerobic training (Clausen and Trap-Jensen, 1969; Redwood et al., 1972; Ehsani et al., 1982; Hagberg et al., 1983). An increase in maximal heart rate may be seen in patients with angina pectoris who have a symptom limited $\dot{V}O_2$ max, and consequently it may contribute to the increased $\dot{V}O_2$ max seen after training. However, in patients who are not symptom limited, maximal heart rate usually stays the same or is reduced. Increases in maximal stroke volume are also rare after training, and have occurred only when the training was unusually intense and prolonged (Hagberg et al., 1983). Therefore, the major mechanism responsible for the increase in $\dot{V}O_2$ max seen after training appears to be a widening of the working muscles AV-O_2d (Detry et al., 1971; Clausen, 1976).

Based on the beneficial circulatory adaptations that occur with aerobic endurance training, this form of exercise has become an integral part of cardiac exercise rehabilitation. As a result, activities of daily living which tax the O_2 transport system, such as walking, are better tolerated by CAD patients.

1.5 Lack of Muscular Strength in CAD Patients

Lack of peripheral muscle strength is often demonstrated in CAD patients during clinical exercise testing in the laboratory. Exercise is frequently terminated because of weak and fatigued leg muscles, with no evidence of central circulatory limitations (McCartney et al., 1989).

Many activities of daily living, such as lifting and carrying loads, rely on considerable peripheral muscular strength and power. Therefore, the typical cardiac training regimen consisting solely of aerobic endurance exercise may inadequately prepare the CAD patient for many activities of daily living. Despite this, the use of strength training in the rehabilitation of CAD patients has traditionally been avoided.

Recently, Oldridge et al. (1989) demonstrated that peripheral muscle weakness could be overcome, at least in part, by intense training on a cycle ergometer. It follows, therefore, that weightlifting training, in conjunction with the conventional aerobic training regimen, may cause greater improvements in the strength and functional capacity of CAD patients than aerobic training alone. McCartney et al. (1991) tested this hypothesis and found that 10 weeks of combined weightlifting and aerobic training in CAD patients resulted in significant increases in upper (42%) and lower (23%) limb strength, compared to non-significant increases following aerobic endurance training alone. In addition, they demonstrated a greater fatigue resistance, and a marked reduction in perceived leg exertion during heavy submaximal exercise, which may transfer to activities of daily living and result in an improved quality of life (McCartney et al., 1991).

The rationale for omitting formal strength training from cardiac rehabilitation programmes has probably been based on the circulatory responses to static exercise in healthy individuals (Donald et al., 1967; Lind, 1970; Shepherd et al., 1981; Hietanen, 1984; Hanson and Nagle, 1987) and in CAD patients (Fisher et al., 1973; Mitchell and Wildenthal, 1974; DeBusk et al., 1978; Markiewicz et al., 1979; Chaney and Arndt, 1983; Mitchell and Blomqvist, 1986; Hanson and Nagle, 1987).

1.6 Circulatory Responses to Static Exercise

Static exercise primarily involves changes in muscle tension, with little change in muscle length (Mitchell and Wildenthal, 1974). The hemodynamic responses to static exercise have been well documented (Alam and Smirk, 1937; Tuttle and Horvath, 1957; Donald et al., 1967; Lind, 1970; Mitchell and Wildenthal, 1974; Asmussen, 1981; Perez-Gonzalez, 1981; Shepherd et al., 1981; Bezucha et al., 1982; Hietanen, 1984). Studies of healthy young subjects have shown that a potent cardiovascular adjustment rapidly occurs during static exercise (Lind et al., 1964; Freyschuss, 1970; Lind, 1983). More specifically, isometric exercise causes a marked increase in systolic, diastolic, and mean arterial pressure. The rise in arterial pressure serves to increase the perfusion pressure to the isometrically contracting muscles in an attempt to overcome the mechanical resistance to muscle blood flow (Lind, 1964; Shepherd et al., 1981). An increase in cardiac output is thought to be the major cause of the increase in arterial pressure

(Shepherd et al., 1981), while total systemic vascular resistance remains relatively constant or increases only slightly (Lind et al., 1964; Lind, 1970; Mitchell and Wildenthal, 1974). Moreover, the increase in cardiac output is thought to be due to an increased heart rate, since stroke volume tends to remain the same or decrease with this form of exercise, as a result of impaired venous return. In the healthy individual, the left ventricular end diastolic and end systolic volumes show little change, and there may be a marked increase in myocardial contractility (Kivowitz et al., 1971; Grossman et al., 1973).

The overall result of these circulatory responses is an increase in the ventricular afterload. Thus, static exercise produces primarily a pressure load on the heart (Mitchell and Blomqvist, 1986). Since the healthy individual has a remarkable reserve capacity, this pressure load is not a major concern. On the other hand, many CAD patients have a poor functional reserve capacity, and static exercise may pose a problem since it evokes increases in blood pressure similar to those seen in healthy individuals. Myocardial contractility does not increase, and cardiac output increases only slightly or does not change. Therefore, an increase in total peripheral resistance is thought to be the major cause of the marked pressor response seen in CAD patients during isometric exercise (Hanson and Nagle, 1987). The increased pressure load on the heart tends to increase the O_2 demands of the left ventricle and this may produce myocardial ischemia in the CAD patient. In addition, left ventricular end diastolic pressure becomes markedly elevated and consequently places the CAD patient at an increased risk of developing pulmonary congestion (Kivowitz et al., 1971; Mitchell and Wildenthal, 1974; Mitchell and Blomqvist, 1986).

1.7 Circulatory Responses to Dynamic Exercise

The circulatory responses to dynamic exercise have been well documented (Tuttle and Horvath, 1957; Clausen, 1976; Asmussen, 1981; Bezucha et al., 1982; Chaney and Arndt, 1983; Mitchell and Blomqvist, 1986).

Activities that are predominantly dynamic include walking, running, swimming, and cycling. Usually a large mass of skeletal muscle is involved, and there is a great demand for O_2 to supply the increased metabolic needs of the contracting muscles (Mitchell and Wildenthal, 1974). The volume of blood being returned to the heart is greater, and therefore, the preload on the heart increases. Cardiac output increases due to an increased heart rate and stroke volume, and there is a marked reduction in total peripheral resistance. This causes relatively little change in mean arterial pressure. Systolic pressure tends to increase, while diastolic pressure does not change or may decrease slightly. The overall result of these circulatory responses to dynamic exercise is a volume load on the heart (Mitchell and Blomqvist, 1986).

Studies have shown that during dynamic exercise at submaximal loads, the ability to increase stroke volume is diminished in many CAD patients, and an increased heart rate may compensate in order to maintain the desired cardiac output (Bruce et al., 1973; Forrester et al., 1977). However, in some CAD patients with evidence of left ventricular failure (Foster et al., 1964) , this compensatory increase in heart rate may not occur, and cardiac output may be abnormally low during submaximal work. This would limit the ability of the heart to deliver O_2 to the exercising muscles, and left ventricular segmental wall motion abnormalities may occur during dynamic exercise (Mitchell and Blomqvist, 1986).

1.8 Circulatory Responses to Dynamic Weightlifting Exercise

Dynamic weightlifting may be defined as a form of combined static and dynamic exercise involving an initial static component, followed by a concentric, and then eccentric contraction, and finally, a relaxation phase of a particular muscle group.

The circulatory responses to weightlifting exercise are different to those seen during pure static or dynamic exercise, and have been examined in healthy individuals (Hurley et al., 1984; MacDougall et al., 1985; Fleck and Dean, 1987; Fleck, 1988; Effron, 1989), and in patients with CAD (Kelemen et al., 1986; Vander et al., 1986; Butler et al., 1987; Featherstone et al., 1987; Harris and Holly, 1987; Haslam et al., 1988; Crozier Ghilarducci et al., 1989; Goldberg et al., 1989; Kelemen, 1989; Stewart et al., 1989; Wiecek et al., 1990; McCartney et al., 1991).

MacDougall et al. (1985) measured intra-arterial pressure directly in a study of healthy young subjects performing heavy lifting to failure, and reported extreme elevations in systolic and diastolic pressures. It was also noted that pressures increased progressively with each subsequent repetition, so that the highest pressures were seen during the final repetitions of the set. In addition, immediately after the last repetition of the exercise, both systolic and diastolic pressures fell below pre-exercise levels. Heart rate was also reported to increase with successive repetitions, reaching a peak during the last few repetitions of a set, and declining thereafter (MacDougall et al. 1985). These results were later supported by Fleck and Dean (1987) in a study of healthy young subjects performing resistance exercise to failure.

Haslam et al. (1988) and Wiecek et al. (1990) measured arterial pressure directly during weightlifting up to 80% of 1 RM in patients with CAD, and found significant but clinically acceptable increases in both systolic and diastolic pressure during lifting, followed by a rapid decline after the final repetition.

Despite the above findings, several studies of weightlifting training in CAD patients have reported little or no increase in arterial pressure with this form of exercise. Kelemen et al. (1986) examined the circulatory responses during circuit weight training in CAD patients, and reported that blood pressure increased only slightly. Blood pressure was measured by auscultation immediately after exercise. Vander et al. (1986) compared the blood pressure responses to weightlifting exercise with those obtained during maximal graded exercise testing, and noted relatively small increases in pressure measured with the cuff method during weightlifting. In a weight training study by Butler et al. (1987), arterial pressure was measured before the start of exercise, immediately after the completion of the first and second weightlifting circuit, and 10 minutes into the recovery period. In addition, blood pressure was measured immediately upon completion of each exercise station. Systolic and diastolic pressures did not increase significantly in this study. Similar results were found in a weight training study by Crozier Ghilarducci et al. (1989), when blood pressure was measured by auscultation at "midlift" for all lower extremity exercises, and immediately after a maximal voluntary contraction for all upper extremity lifts.

The limiting factor common to all of the above mentioned studies is the technique used to measure blood pressure, and the time that the blood pressure was recorded. Recently, Wiecek et al. (1990) compared direct (intra-arterial) and indirect (auscultation) measures of arterial pressure during weightlifting in CAD patients at rest, during, and after various lifting exercises, and concluded that indirect measurements of systolic pressure were significantly less than direct values at rest, and during and after lifting. In addition, they demonstrated that measurements of arterial pressure made by auscultation immediately after lifting do not allow accurate conclusions to be drawn about the arterial pressure generated during lifting due to a rapid fall in pressure that occurs within seconds after exercise (Wiecek et al., 1990).

The increases in arterial pressure seen during dynamic weightlifting exercises have been attributed to a potent pressor response, the mechanical compression of the blood vessels in the contracting muscles, and an elevated intrathoracic pressure caused by the Valsalva maneuver (MacDougall et al., 1990). The exact contribution of the Valsalva maneuver to the total increase in blood pressure is not yet known. However, recently MacDougall et al. (1990) demonstrated that subjects do not find it necessary to perform a Valsalva maneuver unless the intensity of the weightlifting exercise exceeds approximately 80% of 1 RM, or unless repetitions at a lesser intensity are performed to failure.

In summary, traditional cardiac exercise rehabilitation programmes have generally omitted weightlifting training because of the uncertain nature of the circulatory responses to this form of exercise. Recently however, several studies have demonstrated that weightlifting training is safe in patients with uncomplicated CAD, and has proven to be beneficial in terms of improving the patient's strength and functional capacity (Kelemen and Stewart, 1985; Kelemen et al., 1986; Haslam et al., 1988; Stewart, 1989; Franklin et al., 1991; McCartney et al., 1991). In addition, guidelines and recommendations have recently been developed for weightlifting training in CAD patients (Kelemen, 1989; McKelvie and McCartney, 1990; American Association of Cardiovascular and Pulmonary Rehabilitation, 1991).

1.9 Regulation of Arterial Blood Pressure During Exercise: Central and Reflex Neural Mechanisms

The mechanisms that are responsible for the regulation of arterial blood pressure during exercise are not yet completely understood, and have been the subject of a great deal of interest and controversy. Two mechanisms of neural control of the cardiovascular system during exercise have generally been accepted. One mechanism, termed "central command", is a type of feedforward control that arises in a central area of the brain and activates the cardiovascular control areas in the medulla. The cardiovascular centres then determine the amount of sympathetic and parasympathetic activity sent to the heart and blood vessels. In addition, central command is thought to simultaneously feedforward to the motor cortex, where it plays a role in determining the recruitment and firing rates of motor units. Several investigators have suggested that the central command signals originate in an area of the brain termed the subthalamic locomotor region (Eldridge et al., 1981, 1985; Waldrop et al., 1986).

The other mechanism of neural control of the cardiovascular system during exercise is termed the "exercise pressor reflex" or "reflex neural mechanism", and it serves as a type of feedback control. Signals arising in the contracting skeletal muscles are thought to travel along fine afferent fibers, and reflexly activate the cardiovascular control centres in the medulla.

Several studies have been designed in an attempt to identify the muscle afferent fibers that are responsible for the exercise pressor reflex (Coote and Perez-Gonzalez, 1970; McCloskey and Mitchell, 1972; Perez-Gonzalez and Coote, 1972; Tibes, 1977; Kalia et al., 1981; Kniffki et al., 1981; Kaufman et al., 1984), and it has been demonstrated that electrical or chemical activation of group III and IV fibers can cause a marked cardiovascular response (Mitchell et al., 1968; Kaufman et al., 1982).

Group III fibers are thinly myelinated and have a low conduction velocity. The receptors for these fibers are the Paciniform corpuscles and unencapsulated nerve endings, and they are associated with collagen structures in the skeletal muscle (Mitchell, 1990). In a study by Kaufman et al. (1983), it was shown that the majority of group III fibers respond to mechanical events occurring in the muscle during contraction, and they are termed mechanoreceptors (Kaufman et al., 1983).

Group IV fibers are unmyelinated and have a very slow conduction velocity. The receptors for these fibers are unencapsulated nerve endings, and they are associated with blood vessels and lymphatic vessels (Mitchell, 1990). The majority of group IV fibers appear to be stimulated by metabolic changes occurring in the muscle during contraction, and are therefore termed metaboreceptors (Kaufman et al., 1983).

The first attempt to identify the chemical stimulus that activates the receptors of group IV afferent fibers during exercise was made by Lind et al., (1964,1966). Since then, a number of metabolites have been examined, including hydrogen ions, potassium, and prostaglandins (Wildenthal et al., 1968; Rybicki et al., 1984; Stebbins et al., 1986; Rotto et al., 1989). However, the issue remains controversial, and further work needs to be done in order to identify the exact stimulus which activates the unencapsulated nerve endings of group IV muscle afferents.

Studies to determine the area in the medulla responsible for the expression of the reflex mechanism have reported that the ventrolateral medulla is able to produce cardiovascular responses similar to those seen during exercise (Iwamoto et al., 1982; Iwamoto and Kaufman, 1987), and it has been concluded that this area plays an important role in regulating the cardiovascular system during exercise (Mitchell, 1990).

It is evident that many studies have been designed to examine the roles of the central (Alam and Smirk, 1937; Lind et al., 1968; Coote et al., 1971; McCloskey and Mitchell, 1972; Fisher and Nutter, 1974; Mitchell et al., 1977, 1981, 1983; Kniffki et al., 1981; Mitchell, 1985, 1990) and reflex (Goodwin et al., 1972; Mitchell et al., 1981, 1983; Mitchell, 1985, 1990) neural mechanisms in determining the circulatory responses to exercise, and there is support for both types of neural control. Therefore, it is reasonable to accept that the 2 mechanisms are not mutually exclusive, and that they operate in a complementary manner, interacting with each other. In addition, the relative importance of each mechanism has been shown to be dependent upon a number of factors, including the type and intensity of exercise performed, and the effectiveness of blood flow to meet the increased metabolic needs of the contracting muscles (Mitchell, 1990).

1.10 Effects of Weightlifting Training on Arterial Pressure

Recently, McCartney et al. (1989) examined the effects of 12 weeks of progressive weightlifting training on arterial blood pressure responses during lifting in healthy older males, and found that increases in strength after training were associated with reductions in blood pressure during lifting with identical absolute loads. In addition, Sale et al. (1990) studied the effects of 19 weeks of weightlifting training in healthy young males, and reported a similar attenuation of arterial pressure during lifting with identical absolute loads after training. Gibson et al. (1991) later investigated whether this effect of weight training on arterial pressure could be transferred to strength-related activities of daily living in healthy older males, and concluded that there may be a modest transfer of this effect.

If a similar attenuation of the arterial pressure responses to formal lifting should occur in CAD patients following weightlifting training, it may be of considerable functional significance. Moreover, if the reduced responses were also evident during strength related activities of daily living, such as stair climbing, then these tasks could be accomplished with a reduced myocardial O_2 cost, and the practice of weightlifting training in Phase 3 cardiac rehabilitation would assume even greater significance.

1.11 Purpose

The purpose of this thesis was to evaluate the effects of 10 weeks of combined aerobic and weightlifting training on the heart rate and arterial blood pressure responses of CAD patients during formal lifting, and during strength related activities of daily living.

The substantive hypothesis states that following training, there will be a significant: (a) increase in strength of the trained muscles; (b) reduction in the circulatory responses during lifting of identical absolute loads; and (c) reduction in the heart rate and arterial pressure responses during other strength related activities of daily living involving the trained muscles.

CHAPTER 2: METHODS

2.1 Subjects

Males, aged 65 years or less, meeting the inclusion and exclusion criteria (Sections 2.1.1, 2.1.2), and who had regularly attended the McMaster Cardiac Exercise Rehabilitation Programme for at least 2 months prior to the start of the study were considered eligible for entry into the study. Sixteen patients, with a mean age of ($\bar{x} \pm$ SD) 54 $\pm$ 6 years agreed to participate in the study.

The procedures and associated risks were described in detail to the subjects, and signed informed consent (Appendix B) was obtained freely prior to the study in accordance with the regulations issued by the institution's ethics committee. Subjects continued to receive their usual medications throughout the study.

2.1.1 Inclusion Criteria

(a) documented evidence of coronary artery disease including a previous myocardial infarction and/or coronary artery bypass surgery

(b) symptoms of shortness of breath or angina that were no greater than Class I of the New York Heart Association Functional Classification

(c) stable medical therapy

(d) a local resident with transportation to McMaster University

(e) the ability to understand written and verbal instructions

2.1.2 Exclusion Criteria

(a) development of angina or ST segment depression > 1 mm during exercise

(b) development of complex dysrhythmias during exercise

(c) a resting blood pressure > 160 mmHg systolic or 90 mmHg diastolic

(d) an abnormal blood pressure response to clinical exercise testing (a decrease in systolic pressure below resting; a decrease of > 20 mmHg in systolic pressure after the normal exercise increase; maximal systolic pressure in excess of 250 mmHg; an increase in diastolic pressure of > 15 mmHg)

(e) a resting echocardiographic ejection fraction < 50%

(f) evidence of a ventricular aneurysm as documented by echocardiography

(g) a maximum heart rate response < 100 bpm during exercise testing in the absence of beta blocker therapy

(h) respiratory limitation as assessed by pre-exercise pulmonary function evaluation (documented restrictive or obstructive lung disease)

(i) a history of cerebrovascular disease

(j) a major orthopaedic disability

2.2 Experimental Design

Before and after 10 weeks of combined aerobic and weightlifting training, each subject's intra-brachial artery pressure was measured during various arm and leg weightlifting exercises, handgrip dynamometry, treadmill walking and stair climbing (Table 1). Technical difficulties reduced the study cohort to 9 ($\bar{x} \pm$ SD; 53 ± 7 years) at the time of pre-training testing (Table 2). Subjects in the study served as their own controls.

2.3 Testing Protocol

A detailed outline of the testing protocol used to test all subjects before and after the training intervention is displayed in Table 1. The order of exercises was selected at random for each subject.

2.3.1 Maximum Weightlifting Capacity and Isometric Handgrip Strength

The maximum weightlifting capacity of each subject, expressed as one repetition maximum (1 RM), was the heaviest weight in kilograms that the subject could lift once through a full range of movement. Each subject's 1 RM was determined for the seated single-arm curl (SAC), single- (SLP) and double-leg press (DLP) exercises one week prior to the pre-training testing. The maximal voluntary contraction (MVC) of each subject's handgrip strength was also tested at this time.

2.3.2 Intra-arterial Blood Pressure

Intra-arterial blood pressure was measured continuously during the pre- and post-training testing sessions (Table 1). Following infiltration of the skin with local anaesthetic (Xylocaine 2%, Astra Pharmaceuticals, Mississauga, Ontario) the brachial artery of the subject's non-dominant arm was catheterized with a 20-gauge

TABLE 1: TESTING PROTOCOL

Pre-training Measurements

Warm Up

5 min walk on the treadmill at 2.5 mph at 0% grade

Weights

a) 10 reps of single-arm curl at 70% of the subject's 1 RM
b) 12 reps of single-leg press at 80% of the subject's 1 RM
c) 12 reps of double-leg press at 80% of the subject's 1 RM
d) isometric handgrip at 50% of the subject's MVC

Simulated Activities of Daily Living

a) 10 flights on the Stairmaster at 60 steps/min
b) 10 min walk on the treadmill at 3.5 mph at 0% grade, and between mins 4 & 6 and 8 & 10 the subject will carry weights (5 and 10 lbs) in a tote bag using his non-catheterized arm

Post-training Measurements

Warm Up

5 min walk on the treadmill at 2.5 mph at 0% grade

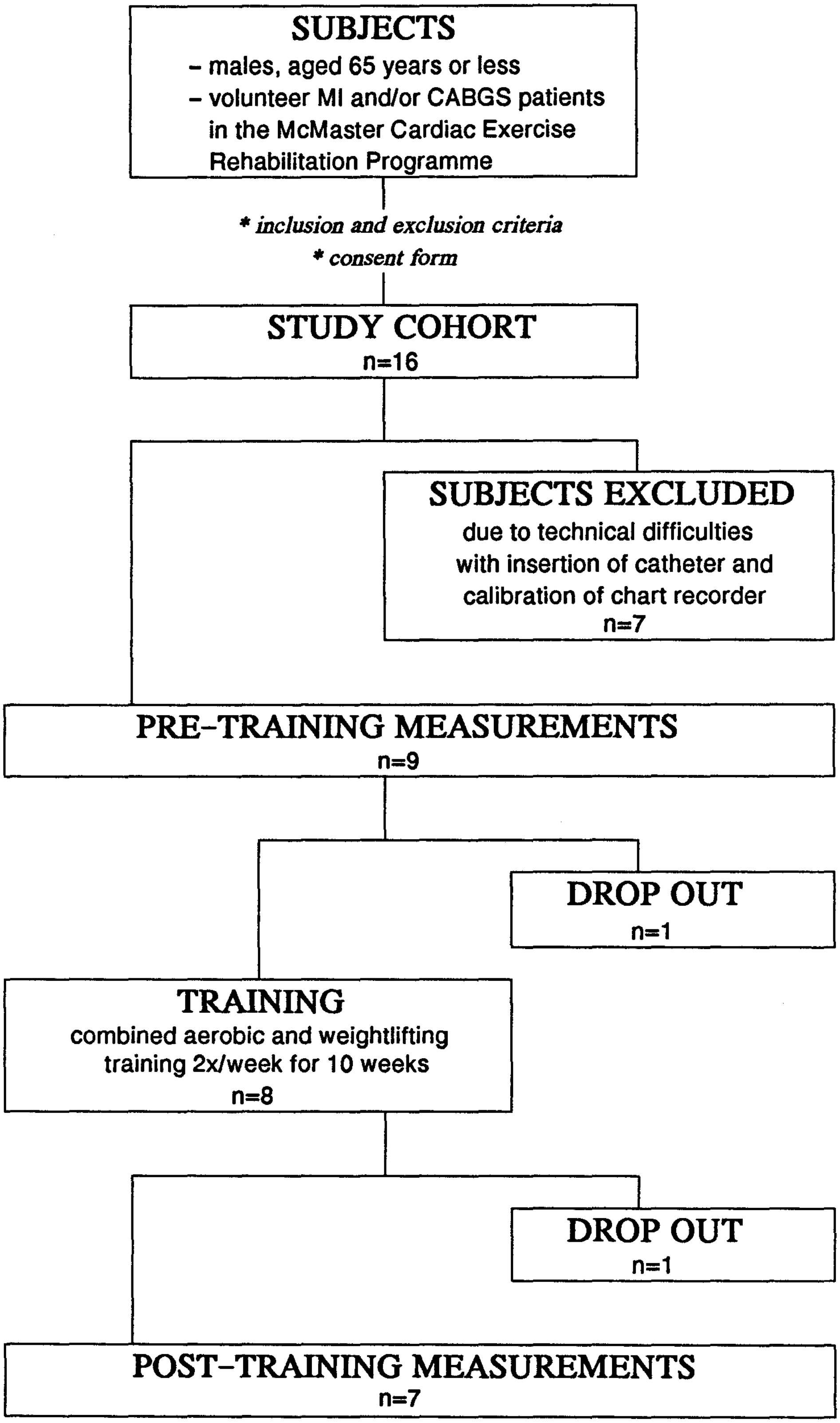
Weights

a) 10 reps of single-arm curl at 70% of the subject's initial 1 RM (same absolute load) and 10 reps at 70% of his new 1 RM (same relative load)
b) 12 reps of single-leg press at 80% of the subject's initial 1 RM and 12 reps at 80% of his new 1 RM
c) 12 reps of double-leg press at 80% of the subject's initial 1 RM and 12 reps at 80% of his new 1 RM
d) isometric handgrip at 50% of the subject's initial MVC and at 50% of his new MVC

Simulated Activities of Daily Living

a) 10 flights on the Stairmaster at 60 steps/min
b) 10 min walk on the treadmill at 3.5 mph at 0% grade, and between mins 4 & 6 and 8 & 10 subject will carry weights (5 and 10 lbs) in a tote bag using his non-catheterized arm

TABLE 2: EXPERIMENTAL DESIGN



Angiocath (Deseret Medical Inc., Parke-Davis and Co., Sandy, UT). Blood pressure was determined using a pressure transducer (MX 800, Medex Inc., Hilliard, OH) adjusted to midsternum level, amplifier (Gould Inc., Instruments Division., Cleveland, OH) and chart recorder (RS3-5P, General Scanning Inc., USA). The system was calibrated statically against a column of mercury, and dynamically using square-wave pressure signals. Direct readings of arterial blood pressure were displayed on the chart recorder.

2.3.3 Weightlifting Testing

Weightlifting testing consisted of 10 repetitions of the seated SAC exercise with the non-catheterized arm at 70% of the subject's 1 RM, and 12 repetitions of the SLP and DLP exercises at 80% of 1 RM. Subjects were encouraged to breathe freely while lifting, and to avoid the Valsalva manoeuvre. A 2 minute recovery period was provided between exercise sets in order to allow the subject's heart rate and blood pressure to return to resting levels.

2.3.4 Treadmill Walking

Each subject walked 10 minutes on the treadmill at 3.5 mph with a 0% grade. Between the 4th and 6th minutes, and 8th and 10th minutes, subjects carried 5 and 10 pound weights respectively, using their non-catheterized arm. Subjects were instructed not to bend or tense the catheterized arm at any time.

2.3.5 Stair Climbing

Subjects climbed 10 flights (160 steps) on a Stairmaster 6000 ergometer (Stairmaster Sports/Medical Products, Newburgh, New York) at a cadence of 60 steps/minute. Once again, subjects were instructed not to bend or tense the catheterized arm throughout the exercise.

2.3.6 Handgrip Dynamometry

Each subject performed an isometric handgrip with the non-catheterized arm at 50% of his maximum voluntary contraction (MVC) for 30 seconds using a handgrip dynamometer. Feedback was provided by the exercise leader in order to ensure the subject worked at the designated intensity.

2.4 Training Intervention

Exercise training sessions were held twice a week for a total of 10 weeks (20 sessions) in the exercise rehabilitation laboratory at McMaster University. Resuscitation equipment was present in the laboratory and the patients were supervised by a physician and an exercise leader at all times.

In each session, subjects trained aerobically according to their regular exercise programme prescription, and they also performed individualized weight training.

The aerobic training regimen consisted of a 5-10 minute warm-up, walking, arm buoys, and arm- and leg-cycling at an intensity equivalent to 70% of functional capacity for approximately 45 minutes. Each training session ended with a

5-10 minute warm-down.

The weightlifting regimen consisted of the SAC and SLP exercises performed by both limbs, in addition to modified trunk curls. The SAC exercise was performed on a seated arm curl weightlifting apparatus (Rubicon Industries, Stoney Creek, Ontario) and the SLP exercise was performed on a Global Gym multistation (4141-162) apparatus (Global Gym Inc., Downsview, Ontario). The order of exercises was selected at random by each subject. The initial weight training protocol consisted of 2 sets of 10 repetitions at 50% of the subject's 1 RM. This was gradually increased throughout the study until subjects were performing 3 sets of 10 repetitions at 70-80% of their current 1 RM (Table 3). Each subject had his 1 RM re-evaluated every 4th training session (Appendix C), and the new training weights were calculated accordingly for the sessions to follow.

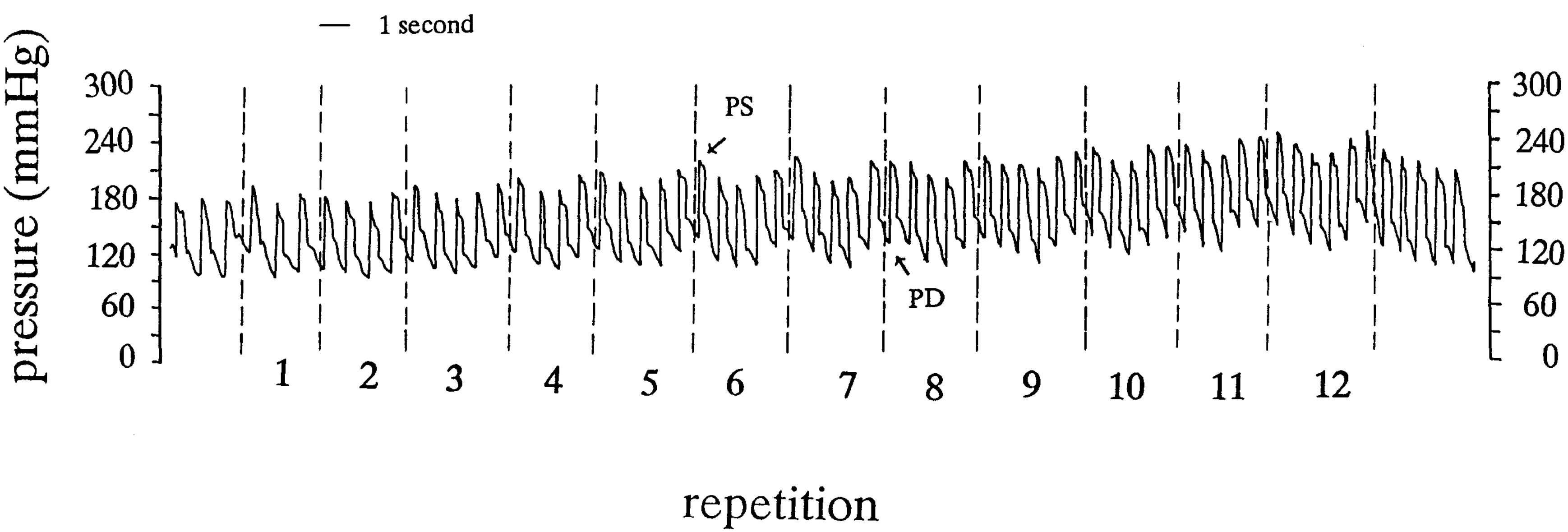
2.5 Data Analysis

A typical intra-arterial blood pressure tracing during lifting (SLP exercise at 80% of 1 RM) is presented in Figure 1. For each weightlifting exercise, peak systolic (PS) and diastolic (PD) pressure was recorded per repetition. In addition, heart rate was calculated by dividing the number of pressure wave forms during each repetition by the time taken to complete that repetition, and mean arterial pressure was estimated from electronically derived pressure integrals. For the stair climbing and treadmill exercises, peak systolic and diastolic pressure, heart rate, and mean arterial pressure was recorded for each flight of stairs, and each minute of exercise, respectively.

TABLE 3: TRAINING PROGRESSION
(2x/week, 10 weeks)

SESSION	REPS	SETS	% 1 RM	SIT UPS
1,2	10	2	50	10
3,4*	10	2	60	10
5,6	10	2	60	10
7,8*	10 10	2 +1	60 70	10
9–12*	10	3	65–70	10
13–16*	10	3	70–80	10
17–20*	10	3	70–80	10

** - reevaluate 1 RM in this session*



1 second
pressure (mmHg)
300
240
180
120
60
0
PS
PD
1
2
3
4
5
6
7
8
9
10
11
12
repetition

2.6 Statistical Analysis

The data were analyzed using either a one- or two- way repeated measures analysis of variance. A probability level of < 0.05 was accepted as statistically significant. A Tukey post hoc test was used to determine the location of significant differences among means. Values are presented as mean $\pm$ standard error of the mean, unless otherwise indicated.

CHAPTER 3: RESULTS

3.1 Subjects

After the initial testing session, 1 subject dropped out of the study because of a back injury that was sustained elsewhere. Another subject was unable to complete the training sessions due to an illness of a family member (Table 2). The remaining 7 subjects successfully completed 20 sessions of training within 12 weeks, and did not experience any related injuries or episodes of chest pain or dyspnea. During pre- and post-training testing, there were no abnormal blood pressure responses, significant dysrhythmias, or ischemic electrocardiographic changes.

The subjects that completed the training were comparable with respect to age, height, weight, number of months in the Chedoke-McMaster Cardiac Exercise Rehabilitation Programme, and evidence of a myocardial infarction within the past 12 months. All subjects were taking ASA, 5 were taking beta-blockers, 3 took calcium antagonists, and 5 used nitroglycerin as required (Table 4).

Problems with the brachial artery catheter excluded 1 subject from post-training testing on the Stairmaster ergometer and therefore, his pre-training data for stair climbing were not included in the descriptive statistics or the analysis.

TABLE 4: SUBJECT CHARACTERISTICS

SUBJECT	*DIAGNOSIS*	*MEDICATION*	*DATE OF BIRTH* (y/m/d)	*HEIGHT* (cm)	*WEIGHT* (kg)
A	MI (May 1988) MI (Nov 1988) MI (Jun 1989)	* Atenolol - 25mg OD Diltiazem - 60mg QID Cedocard - 20mg BID ASA - 325mg OD Nitro (paste) - 2% BID	37/05/09	169	83
B	MI (Apr 1989)	* Atenolol - 50mg OD ASA - 325mg OD	29/11/19	187	79
C	MI (Jul 1989)	* Atenolol - 25mg OD ASA - 325mg OD Nitro spray	42/12/11	184	88
D	MI (Jun 1989)	* Nadolol - 80mg OD ASA - 325mg OD Nitro PRN	35/04/09	164	96
E	MI (Feb 1989)	Cardizem - 150mg BID ASA - 325mg OD Nitro spray	37/02/08	176	80
F	MI (Sep 1982) MI (Nov 1989)	Diltiazem HCL - 30mg QID ASA - 325mg OD Nitrong SR - 2.6mg TID Nitro spray	33/03/11	175	76
G	MI (Dec 1989)	* Atenolol - 25mg OD ASA - 325mg OD	42/06/08	177	86

* beta blocker

3.2 Effects of the Exercise Training Programme on Maximum Isometric Handgrip Strength, and Weightlifting Capacity

3.2.1 Maximum Isometric Handgrip Strength

Maximum isometric handgrip strength of the dominant hand increased 20% (46 ± 3 vs 55 ± 4 kg; $p < 0.017$) after training (Fig. 2).

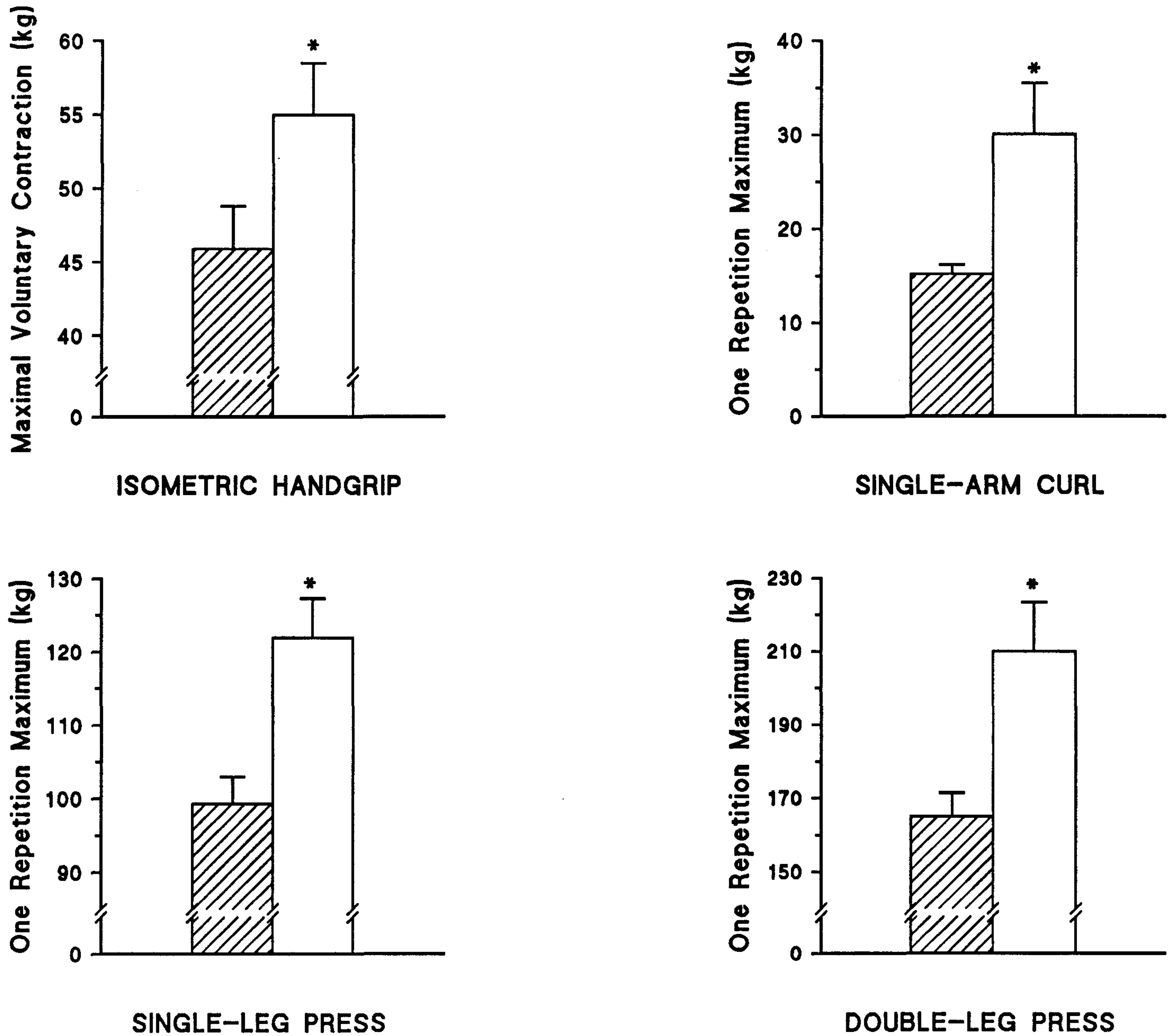
3.2.2 Maximum Weightlifting Capacity

Following training, the 1 RM's for the SAC, SLP, and DLP exercises increased 98% (15 ± 1 vs 30 ± 5 kg; $p < 0.016$), 23% (99 ± 4 vs 122 ± 5 kg; $p < 0.002$), and 27% (165 ± 6 vs 210 ± 13 kg; $p < 0.001$) respectively (Fig. 2).

3.3 Effects of the Exercise Training Programme on Arterial Pressure and Heart Rate

3.3.1 Resting Comparisons

Pre- and post-training resting values for peak systolic pressure (162 ± 8 vs 161 ± 8 mmHg), peak diastolic pressure (88 ± 3 vs 90 ± 4 mmHg), mean arterial pressure (110 ± 5 vs 111 ± 5 mmHg), heart rate (63 ± 5 vs 65 ± 4 bpm), and rate pressure product (102 ±9 ($x10^2$) vs 106 ± 9 ($x10^2$)) were not significantly different.


Maximal Voluntary Contraction (kg)
ISOMETRIC HANDGRIP
One Repetition Maximum (kg)
SINGLE-ARM CURL
One Repetition Maximum (kg)
SINGLE-LEG PRESS
One Repetition Maximum (kg)
DOUBLE-LEG PRESS

3.3.2 During Lifting with the Same Absolute and Relative Load

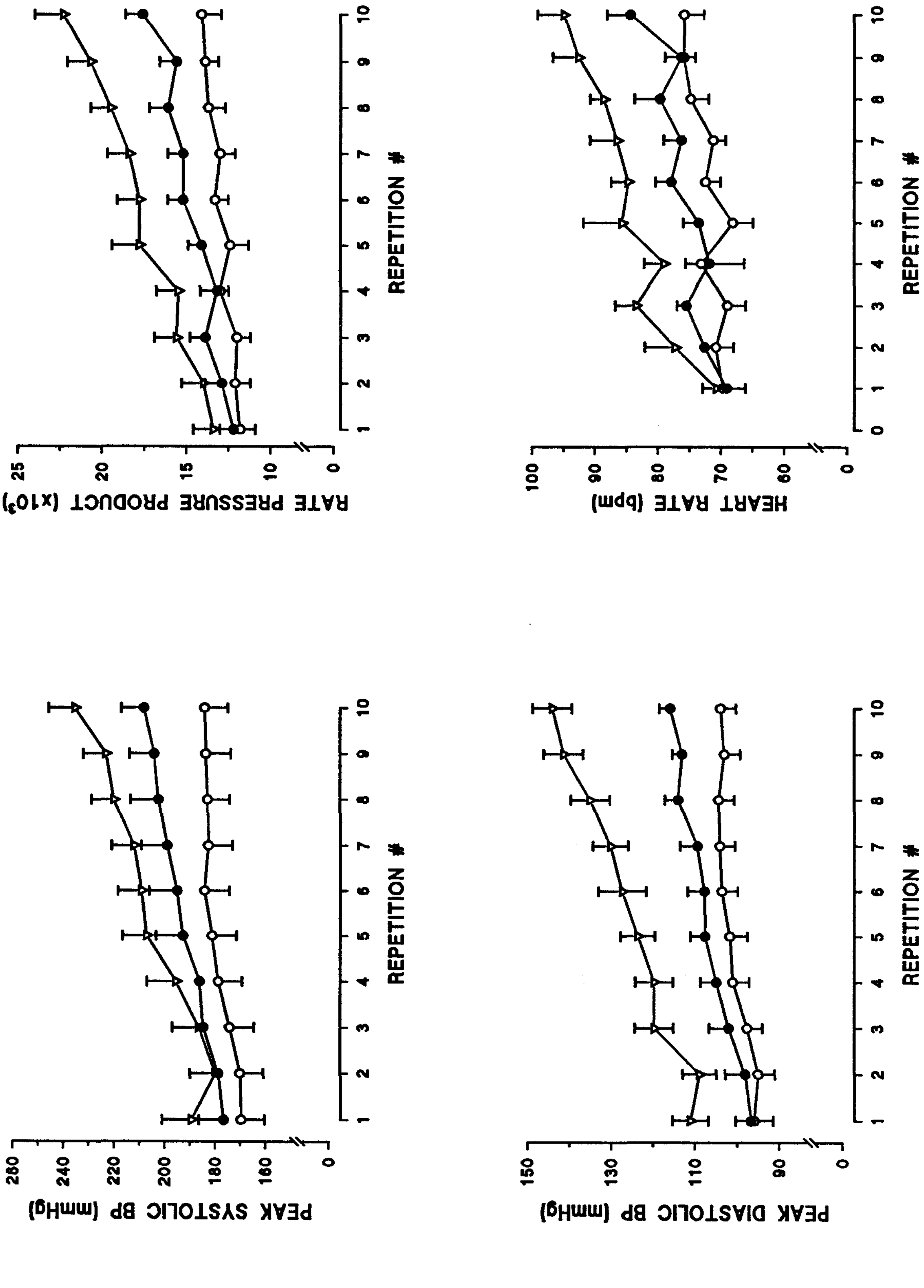
3.3.2.1 Peak Systolic Pressure

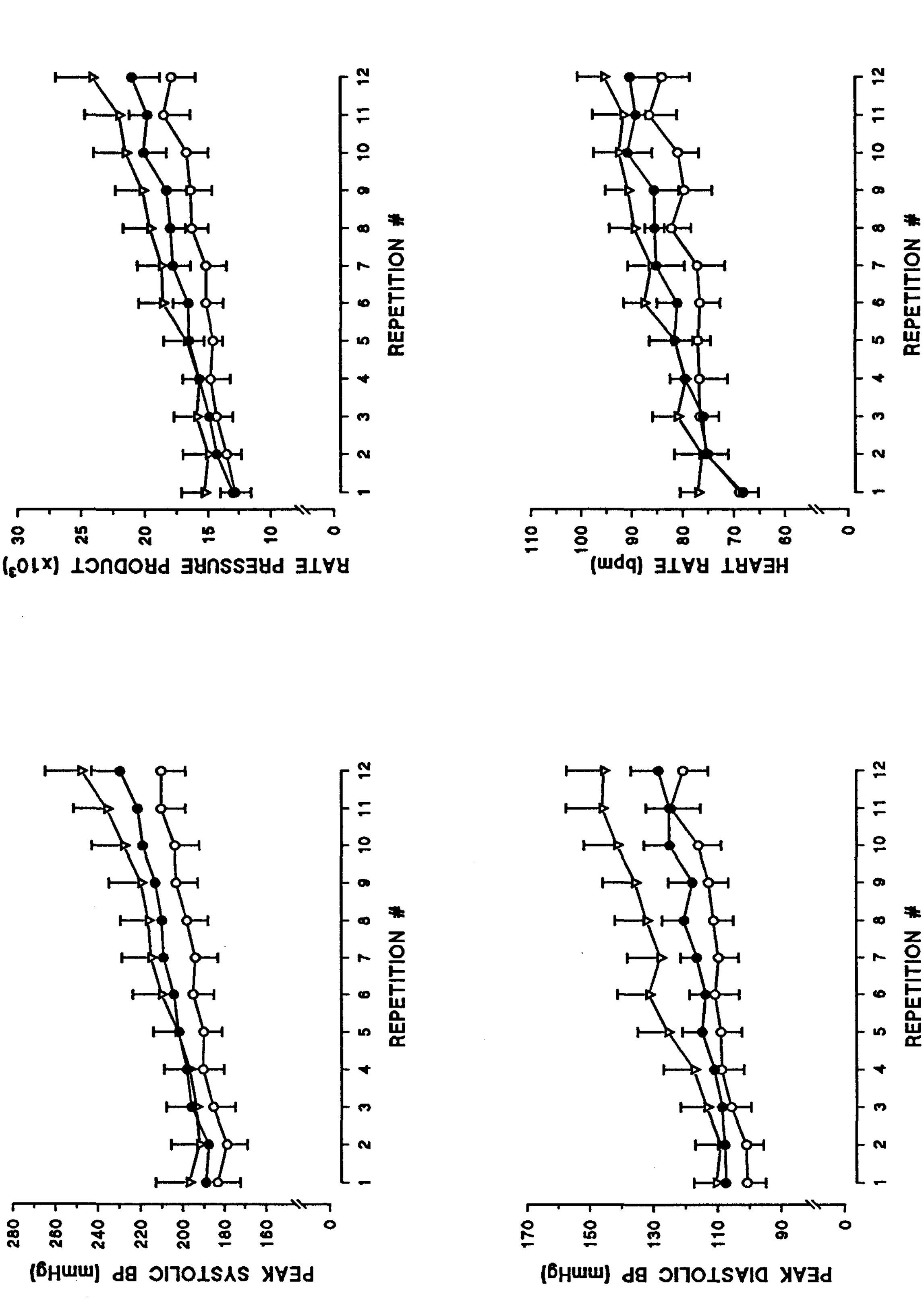
After training, the mean peak systolic pressure in the SAC, SLP, and DLP exercises decreased when subjects lifted the same absolute load (70% of the pre-training 1 RM for SAC exercise, and 80% of the pre-training 1 RM for the SLP and DLP exercises). This decrease was significant ($p < 0.001$) after repetition 3 in the SAC exercise, after repetition 2 in the SLP, and after repetition 6 in the DLP exercise (Figs. 3, 4, 5).

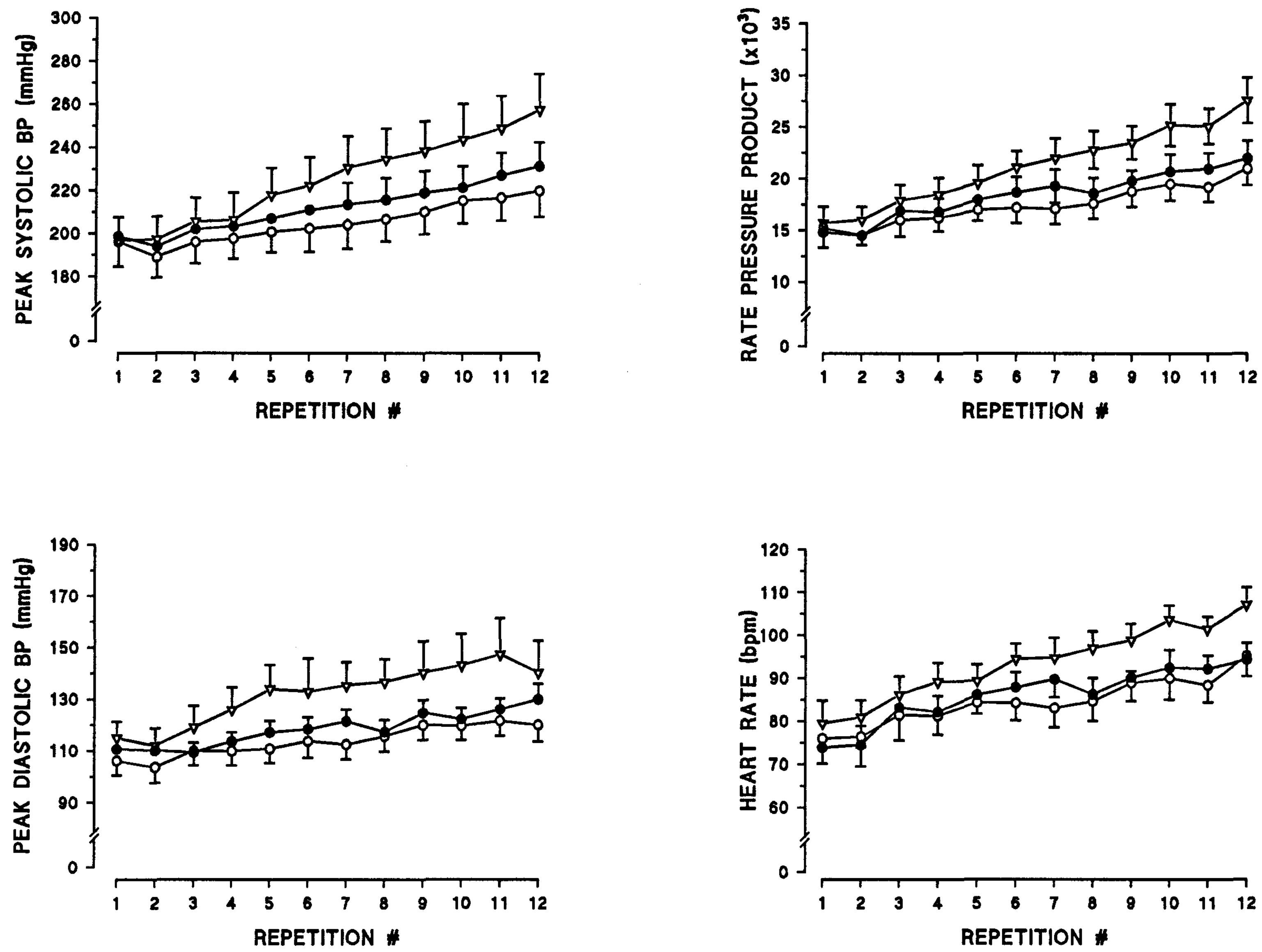
When subjects lifted the same relative load (70% of the post-training 1 RM for the SAC exercise, and 80% of the post-training 1 RM for the SLP and DLP exercises) after training, the mean peak systolic pressure in all 3 weightlifting exercises increased. This increase was significant ($p < 0.001$) for repetition 1 and after repetition 4 in the SAC exercise, after repetition 10 in the SLP exercise, and after repetition 5 in the DLP exercise (Figs. 3, 4, 5).

3.3.2.2 Peak Diastolic Pressure

After training, the mean peak diastolic pressure in all 3 weightlifting exercises was reduced when subjects lifted the same absolute load. This decrease was significant ($p < 0.005$) after repetition 8 in the SAC exercise, for repetitions 8 and 10 in the SLP exercise, and for repetitions 7 and 12 in the DLP exercise.


PEAK SYSTOLIC BP (mmHg)
RATE PRESSURE PRODUCT (x10³)
PEAK DIASTOLIC BP (mmHg)
HEART RATE (bpm)
REPETITION #
REPETITION #
REPETITION #
REPETITION #


PEAK SYSTOLIC BP (mmHg)
RATE PRESSURE PRODUCT (x10³)
PEAK DIASTOLIC BP (mmHg)
HEART RATE (bpm)
REPETITION #


PEAK SYSTOLIC BP (mmHg)
300
280
260
240
220
200
180
0
1 2 3 4 5 6 7 8 9 10 11 12
REPETITION #
RATE PRESSURE PRODUCT (x10³)
35
30
25
20
15
10
0
1 2 3 4 5 6 7 8 9 10 11 12
REPETITION #
PEAK DIASTOLIC BP (mmHg)
190
170
150
130
110
90
0
1 2 3 4 5 6 7 8 9 10 11 12
REPETITION #
HEART RATE (bpm)
120
110
100
90
80
70
60
0
1 2 3 4 5 6 7 8 9 10 11 12
REPETITION #

When subjects lifted the same relative load after training, the mean peak diastolic pressure increased in all 3 lifting exercises. This increase was significant ($p < 0.005$) throughout the SAC exercise, after repetition 5 in the SLP exercise, and after repetition 3 in the DLP exercise (Figs. 3, 4, 5).

3.3.2.3 Mean Arterial Pressure

After training, MAP was reduced in all 3 weightlifting exercises when subjects lifted the same absolute load, but this decrease was not significant (Fig. 6).

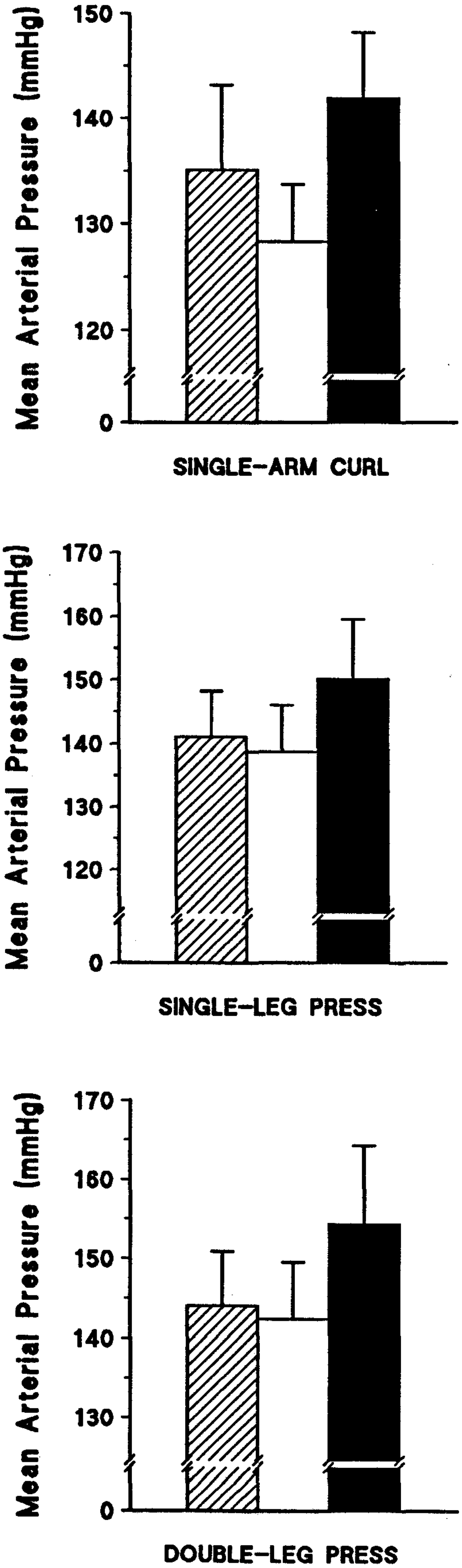
When subjects lifted the same relative load after training, MAP increased in all 3 weightlifting exercises, but this increase was also not significant (Fig. 6).

3.3.2.4 Heart Rate

There was an attenuated heart rate response after training in all 3 weightlifting exercises when subjects lifted the identical absolute load, but this decrease was not significant (Figs. 3, 4, 5). However, a significant increase in the overall average HR was seen during the SAC (75 ± 2 vs 82 ± 3 bpm; $p < 0.002$), SLP (80 ± 2 vs 86 ± 4 bpm; $p < 0.016$), and DLP (86 ± 3 vs 93 ± 4 bpm; $p < 0.01$) exercises when subjects lifted the same relative load (Figs. 3, 4, 5).

3.3.2.5 Rate Pressure Product

The mean maximal RPP in each weightlifting exercise was reduced after training when subjects lifted identical absolute loads. This decrease was significant


Mean Arterial Pressure (mmHg)
150
140
130
120
0
SINGLE-ARM CURL
Mean Arterial Pressure (mmHg)
170
160
150
140
130
120
0
SINGLE-LEG PRESS
Mean Arterial Pressure (mmHg)
170
160
150
140
130
0
DOUBLE-LEG PRESS

($p < 0.001$) for repetitions 7, 8 and 10 in the SAC exercise, after repetition 5 (excluding 6, 8 and 11) in the SLP exercise, and for repetitions 7 and 11 in the DLP exercise (Figs. 3, 4, 5).

When subjects lifted the same relative load after training, the mean maximal RPP in each weightlifting exercise increased. This was significant ($p < 0.001$) after repetition 4 in the SAC, for reps 1, 6, 9, 11, and 12 in the SLP exercise, and after repetition 6 in the DLP exercise (Figs. 3, 4, 5).

3.3.2.6 Effect of Repetitions

In all 3 weightlifting exercises, for each condition, the peak systolic and diastolic pressure, HR, and the RPP increased significantly ($p < 0.001$) with successive repetitions (Figs. 3, 4, 5).

3.3.3 During Handgrip Dynamometry with the Same Absolute and Relative Load

Post-training isometric handgrip measurements at the same absolute load (50% of the pre-training 1 MVC) and the same relative load (50% of the post-training 1 MVC) were not significantly different from pre-training measurements for peak systolic pressure (197 ± 10 vs 188 ± 11 vs 193 ± 12 mmHg), peak diastolic pressure (105 ± 3 vs 99 ± 5 vs 108 ± 6 mmHg), MAP (127 ± 6 vs 120 ± 9 vs 124 ± 10 mmHg), HR (72 ± 3 vs 73 ± 5 vs 75 ± 4 bpm) and RPP (142 ± 8 (x 10^2) vs 137 ± 13 (x 10^2) vs 146 ± 13 (x10^2)).

3.3.4 During Treadmill Walking with and without Handheld Weights

3.3.4.1 Peak Systolic Pressure

The average peak systolic pressure during treadmill walking decreased by 5% (201 ± 1 vs 191 ± 2 mmHg) after training. The decrease was significant ($p < 0.043$) for the first 9 minutes of treadmill walking. The handheld weights did not produce any greater decreases in pressure after training (Fig. 7).

3.3.4.2 Peak Diastolic Pressure

The average peak diastolic pressure decreased overall by 4% (94 ± 1 vs 90 ± 1 mmHg; N.S.) after training (Fig. 7).

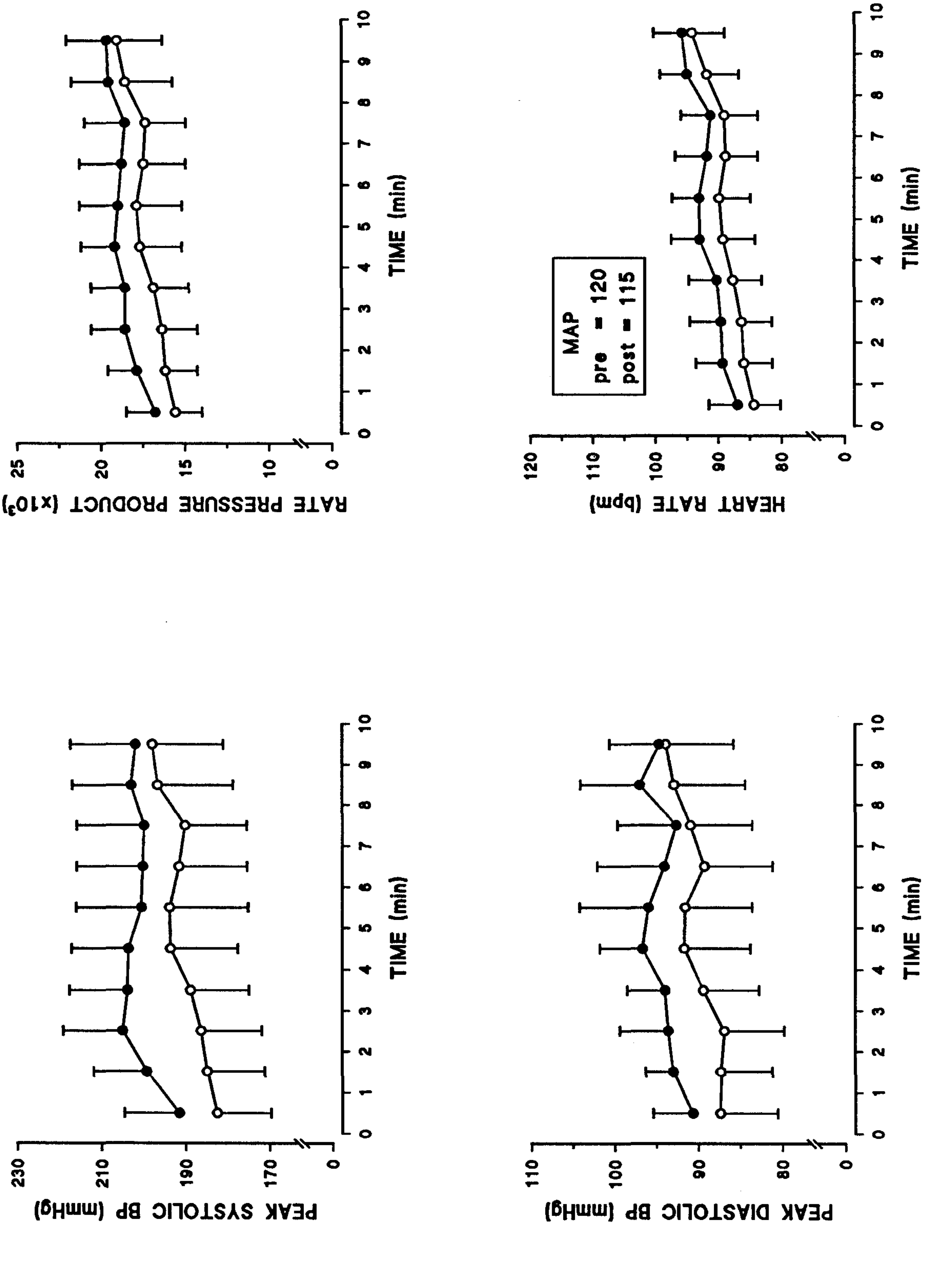
3.3.4.3 Mean Arterial Pressure

There was a 4% reduction in MAP (120 ± 8 vs 115 ± 10 mmHg; N.S.) during treadmill walking after training.

3.3.4.4 Heart Rate

There was an overall reduction of 3% in average HR (92 ± 1 vs 89 ± 1 bpm; N.S.) after training.

HR increased significantly ($p < 0.001$) from the 1st to the 10th minutes of treadmill walking (Fig. 7).


PEAK SYSTOLIC BP (mmHg)
TIME (min)
RATE PRESSURE PRODUCT (x10³)
TIME (min)
PEAK DIASTOLIC BP (mmHg)
TIME (min)
HEART RATE (bpm)
TIME (min)
MAP
pre = 120
post = 115

3.3.4.5 Rate Pressure Product

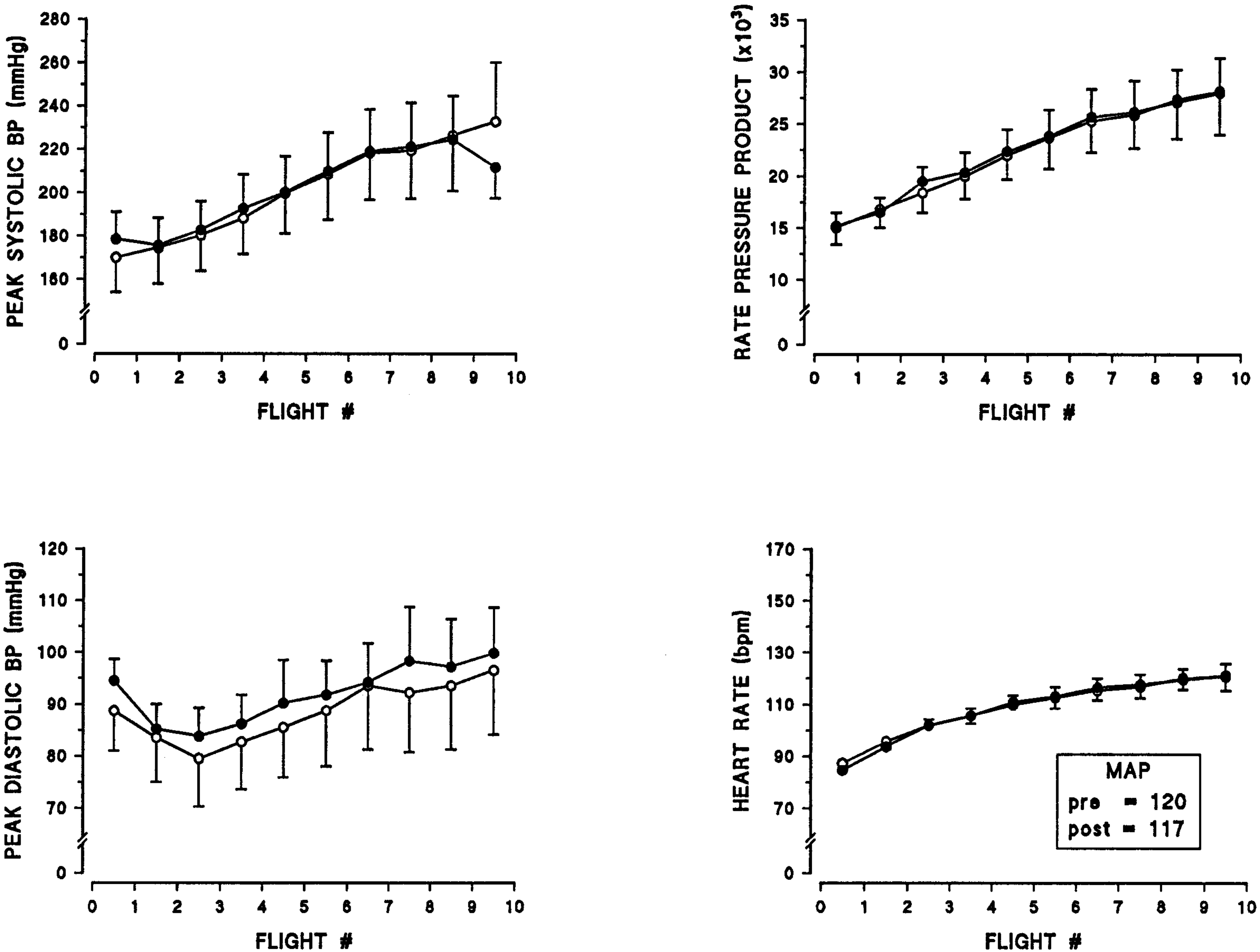
After training, there was an overall non-significant reduction in the RPP (187 ± 3 (x10^2) vs 173 ± 3 (x10^2)).

From the 1st to the 10th minutes of treadmill walking, the RPP increased significantly ($p < 0.013$) (Fig. 7).

3.3.5 During Stair Climbing

Pre- and post-training values for peak systolic pressure (202 ± 6 vs 202 ± 7 mmHg), peak diastolic pressure (92 ± 2 vs 88 ± 2 mmHg), MAP (120 ± 10 vs 117 ± 12 mmHg), HR (108 ± 4 vs 109 ± 3 bpm), and RPP (225 ± 14 (x10^2) vs 223 ± 1 (x10^2)) were not significantly different (Fig. 8).

Peak systolic and diastolic pressure, HR and RPP increased significantly ($p < 0.006$) with successive flights (Fig. 8).


PEAK SYSTOLIC BP (mmHg)
FLIGHT #
RATE PRESSURE PRODUCT (x10³)
FLIGHT #
PEAK DIASTOLIC BP (mmHg)
FLIGHT #
HEART RATE (bpm)
MAP
pre = 120
post = 117
FLIGHT #

CHAPTER 4: DISCUSSION

4.1 Introduction

Cardiac exercise rehabilitation programmes have traditionally emphasized relatively low intensity dynamic exercises with large muscle groups, such as walking and stationary cycling. The benefits of aerobic endurance training in CAD patients have been well documented (Detry et al., 1971; Clausen, 1976; Amsterdam et al., 1981; Ehsani et al., 1982; Hagberg et al., 1983; Oldridge et al., 1989).

More recently, however, the benefits of weightlifting training in CAD patients have been recognized, and include increases in strength, aerobic power, and cardiovascular endurance, as well as a decreased perception of effort during exercise, and an overall improvement of psychosocial well being (Kelemen et al., 1986; Stewart et al., 1988; Crozier Ghilarducci et al., 1989; Stewart, 1989; McCartney et al., 1991). In addition, evidence from studies of healthy individuals has recently been accumulated (McCartney et al., 1989; Sale et al., 1990; Gibson et al., 1991), and suggests that there may be another potential benefit - that is, a reduced heart rate and arterial pressure response in CAD patients during weightlifting with identical absolute loads after training.

Since the product of heart rate and systolic arterial pressure, or "rate pressure product", is directly related to myocardial O_2 requirements, it can be considered an index of myocardial O_2 cost. It follows, therefore, that a training-induced attenuation of heart rate and arterial pressure would allow CAD patients to lift identical absolute loads after training with less strain on the heart, and with a greater cardiac reserve. Thus, the potential exists for CAD patients to perform weightlifting exercises and strength related activities of daily living with a lower rate pressure product and myocardial O_2 cost. This implies that symptom limited CAD patients may experience fewer episodes of angina throughout the day, and consequently improve their quality of life.

It may be hypothesized that the training-induced attenuations of heart rate and arterial pressure seen during weightlifting are due to a reduction in the "central drive" that activates the motor cortex and the cardiovascular control centres in the medulla. After weight training, a given absolute load should represent a lower % of the subject's 1 RM, providing that strength gains have occurred as a result of the training. Therefore, less effort or "central command" should be required to lift the weight, and consequently, the magnitude of the pressor response should not be as great. On the other hand, when a subject lifts a weight that corresponds to the same relative intensity, the magnitude of the pressor response should not change, or may even increase, due to the increased size of the active muscle mass within that individual, and the greater intramuscular tension produced.

These findings may have important implications for CAD patients, and could influence the way that exercise is prescribed in cardiac rehabilitation programmes;

for example, there may be a greater emphasis on strength training rather than on traditional aerobic endurance training.

4.2 Purpose

The purpose of this thesis investigation was to determine 1) whether increases in strength after weight training would be associated with reductions in heart rate and blood pressure during weightlifting with identical absolute loads in CAD patients, and 2) whether this effect could be transferred to strength related activities of daily living.

4.3 Maximum Isometric Handgrip Strength and Weightlifting Capacity

Handgrip strength increased significantly after training despite the fact that this exercise was not included in the training regimen. The increase in strength was seen in both hands, and therefore, it may have resulted from subjects training on the arm curl weightlifting apparatus, since the SAC exercise involved many of the same muscles used in handgrip dynamometry.

As in previous studies of weightlifting training in CAD patients (Kelemen et al., 1986; Stewart et al., 1988; Crozier Ghilarducci et al., 1989; Stewart, 1989; McCartney et al., 1991), and healthy young (Hurley et al., 1984; Sale et al., 1990), and older males (McCartney et al., 1989; Brown et al., 1990; ; Gibson et al., 1991), substantial increases in 1 RM strength occurred in all exercises as a result of weight training. It was not the purpose of this thesis investigation to elucidate the mechanisms responsible for the increases in strength. Recently however, Brown et al., (1991) studied the adaptations to 12 weeks of progressive weightlifting training in the elderly, and demonstrated increases in whole muscle mass, individual fibre cross-sectional area, and the mean area of type II muscle fibres.

4.4 Effects of the Training Programme on the Circulatory Responses During Weightlifting

After training, the mean peak systolic and diastolic pressures in each weightlifting exercise were reduced when subjects lifted the same absolute loads. Since significant increases in strength occurred as a result of weight training, a given absolute load represented less of a relative load after training. Muscle hypertrophy, associated with resistance training, should result in the activation of fewer muscle fibres for any given power output. Therefore, less central drive may be required by the subject to generate a given absolute force, and the magnitude of the pressor response would decrease. Consistent with such a conclusion is the recent suggestion by MacDougall et al. (1990), that the magnitude of the blood pressure response during weightlifting is related to the intensity of effort (% 1 RM), and is independent of the absolute force produced by the muscle.

The mean maximal rate pressure product in each weightlifting exercise was also reduced after training when subjects lifted identical absolute loads. These results indicate that the subjects' myocardial O_2 requirements had decreased for a given absolute load, and therefore, less strain was being placed on the heart with a concomitantly greater cardiac reserve.

When subjects lifted the same relative load after training, mean peak systolic and diastolic pressures, heart rate, and rate pressure product increased in all 3 weightlifting exercises. These findings are in agreement with results from similar weightlifting studies in healthy males (Sale et al., 1990; Gibson et al., 1991), but contrast those previously found by McCartney et al. (1989), who reported little change in the mean peak arterial pressure responses during lifting with identical relative loads after training. One possible explanation for the increased heart rate and blood pressure responses seen after training in this study could be that the 1 RM's recorded before training were not truly maximal. This could have resulted from subject anxiety or lack of familiarity with weightlifting, despite efforts by the investigator to minimize such potential complications. In this event, the loads lifted, and the associated circulatory responses during pre-training testing, would have been underestimated. An assumption underlying this explanation is that by the time of post-training testing, subjects were able to produce a true 1 RM. Alternatively, the increased pressor response seen during lifting at the same relative intensity after training may be attributed to an enhanced intramuscular mechanical compression of the vasculature associated with the heavier load, and possibly the contraction of a larger muscle mass due to the training. In this situation, the total peripheral resistance consequently increases, and greater arterial pressures are produced.

These data suggest that the size of the active muscle mass within each subject influences the magnitude of the blood pressure increase seen during exercise. However, MacDougall et al. (1985) have demonstrated that this is not a direct relationship; for example, the peak blood pressure generated during a double-leg press was only slightly higher than that generated during a single-leg press at the same relative intensity (MacDougall et al., 1985).

4.5 Effects of the Training Programme on the Circulatory Responses During Treadmill Walking

The attenuated circulatory responses seen during repeated lifting with identical absolute loads after training appeared to transfer over to certain activities of daily living. However, the transfer of this effect was modest; all circulatory responses during 10 minutes of treadmill walking were reduced, but only systolic blood pressure decreased significantly after training. The modest transfer of the attenuated pressor response to exercise may be explained by the fact that treadmill walking involves several muscle groups, and the subjects in this study only trained one of these muscle groups. A greater transfer may have occurred if more muscles involved in treadmill walking were strength trained. Nevertheless, if the magnitude of the blood pressure response is related to the degree of effort, or central drive, and even if only slightly less effort is required to produce the same amount of work after training (i.e. 10 minutes of treadmill walking), then the magnitude of the pressor response may be reduced, even if the reduction is only slight.

It should be noted that, in addition to the weight training protocol, subjects also trained aerobically. Therefore, the decreased circulatory responses to treadmill walking after training may have been due, at least in part, to the effects of the aerobic endurance training.

4.6 Effects of the Training Programme on the Circulatory Responses During Stair Climbing

A greater attenuation of heart rate and arterial pressure responses might have been expected during stair climbing than during treadmill walking, due to the greater involvement of the knee extensor muscles. However, the circulatory responses during stair climbing did not change significantly after training. Gibson et al. (1991) reported similar findings in a weight training study of healthy older males. The most likely explanation for these findings is that the exercise responses during stair climbing were up to 100% of the predicted maximum for these subjects, and few studies have demonstrated reduced circulatory responses during maximal exercise after training.

The results in this study may also reflect the importance of specificity of training. Sale and MacDougall (1981) reviewed the scientific evidence in relation to specificity of training, and concluded that strength training should be as specific as possible; that is, the training exercises should simulate the target movement as closely as possible, in relation to movement pattern, velocity of movement, muscular contraction type, and contraction force (Sale and MacDougall, 1981). It follows, therefore, that weight training exercises should also closely simulate strength related activities of daily living, such as stair climbing, if one expects to see training-induced attenuations of the circulatory responses during these activities.

CHAPTER 5: SUMMARY AND RECOMMENDATIONS

5.1 Summary

Traditional cardiac exercise rehabilitation programmes have generally omitted weightlifting training due to the uncertain nature of the circulatory responses during this form of exercise. Recently however, several studies have demonstrated that weightlifting is safe in patients with uncomplicated CAD, and significant but clinically acceptable increases in blood pressure are generated during lifting. Furthermore, weightlifting training has proven to be beneficial in terms of improving the patients' strength and functional capacity, and therefore, has become an accepted practice in many cardiac exercise rehabilitation programmes.

The mechanisms responsible for the circulatory responses during exercise are not yet completely understood. Two neural mechanisms of cardiovascular control, central command and the exercise pressor reflex, have generally been accepted. Central command is a type of feedforward control, and involves signals that arise in a central area of the brain, and that stimulate the motor cortex and the cardiovascular control centres in the medulla. The exercise pressor reflex is a type of feedback control, involving signals that arise in the contracting skeletal muscles which reflexly activate the same cardiovascular control areas in the medulla.

There is support for both types of neural control, and it would appear that the two mechanisms are not mutually exclusive; instead, it is thought that they operate in a complementary manner, regulating the circulatory responses to exercise.

The effect of weightlifting training on the circulatory responses of CAD patients during formal lifting and during strength related activities of daily living has been the focus of this thesis. The substantive hypothesis stated that increases in strength after weight training would be associated with reductions in circulatory responses during: 1) weightlifting with identical absolute loads; and 2) strength related activities of daily living.

After 10 weeks (20 sessions) of combined aerobic and weightlifting training, maximum isometric handgrip strength increased 20% ($p < 0.017$), and the 1 RM's for the SAC, SLP, and DLP exercises increased 98% ($p < 0.16$), 23% ($p < 0.002$), and 27% ($p < 0.001$) respectively.

The results of this study demonstrated training-induced attenuations of the circulatory responses during lifting of identical absolute loads after training. These responses were most likely mediated by a reduction in central command, or the degree of effort required for the muscle involved to generate a given force.

When subjects lifted the same relative load after training, the circulatory responses were greater. This may be attributed to a greater mechanical compression of the vasculature associated with the heavier load, and possibly the contraction of a larger muscle mass consequent to the training.

A modest transfer of the attenuated circulatory responses was evident during treadmill walking, and no transfer was seen during stair climbing. This may be explained by the fact that the weightlifting training in this study did not simulate these activities of daily living very closely, and therefore, the benefits of specific training may have been lost.

5.2 Recommendations

Further research in this area may be enhanced by reviewing some of the limitations of this study, and taking the following recommendations into consideration. Future studies should include a matched control group, a larger sample size, and perhaps a longer period of training. In addition, specificity of training should be emphasized by training more of the muscle groups involved in the activities of daily living to be tested.

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CHAPTER 6:

APPENDICES

APPENDIX A:

Comparison of Direct and Indirect Measures of
Systemic Arterial Pressure During Weightlifting
In Coronary Artery Disease

Wiecek E, McCartney N, McKelvie R. Comparison of Direct and Indirect Measures of Systematic Arterial pressure During Weightlifting in Coronary Artery Disease. *The American Journal of Cardiology* 1990; 1064-1069.

APPENDIX B:

Consent Form

E.C.G. and Arterial Blood Pressure Responses to Weightlifting Exercise

1. I,____________________ consent to take part in a study which will examine the effects of arm and leg weightlifting training on exercise performance, and on the heart rate and arterial blood pressure responses of cardiac patients during formal lifting and during selected simulated activities of daily living performed in the cardiac exercise rehabilitation laboratory. The study involves 12 weeks of weightlifting training and aerobic training and pre- and post-training measures of blood pressure and heart rate during various exercises.

2. Dr. Neil McCartney, Ph.D., the principal investigator and/or Elizabeth Wiecek, B.P.E., has informed me that I will be assigned to a combined aerobic and weightlifting training group. During the pre- and post-testing sessions, a catheter will be inserted into the brachial artery of my non-exercising arm, where it will remain throughout the exercise procedures. I have been informed that Dr. Robert McKelvie, M.D. will be the physician responsible for inserting the catheter and providing medical care.

3. There may be some slight bruising from the catheter, but this should disappear in about one day. I understand that there may be an increased risk of a cardiac event while exercising, but that this risk is very small. I further understand that emergency equipment is available at all times in the laboratory, and that Dr. McKelvie will always be present during the testing sessions should such an event happen.

4. I understand that I may withdraw from the study at any time, even after signing this form, without prejudice. Any information that is collected about me during this study will be kept confidential, and if the results are published, I will not be identified in any way.

5. ____________________ ____________________ __________
Subject Name (print) Signature Date

6. ____________________ ____________________ __________
Witness Signature Date

7. I have explained the nature of the study to the patient and believe he has understood it.

____________________ ____________________ __________
Principal Investigator Signature Date

APPENDIX C:

One Repetition Maximum Evaluations
During Training

1 RM EVALUATIONS DURING TRAINING

Subject A

	Handgrip (kg)		SAC (kg)		SLP (kg)		DLP (kg)
	left	right	left	right	left	right	
Pre-training	42	50	14.85	15.50	95	95	165
Session 04	42	50	15.60	16.25	100	100	180
Session 08	42	50	16.35	16.25	105	105	190
Session 12	42	50	18.85	21.25	120	120	200
Session 16	42	50	23.85	28.75	120	120	210
Post-training	42	50	23.85	28.75	120	120	210

Subject B

	Handgrip (kg)		SAC (kg)		SLP (kg)		DLP (kg)
	left	right	left	right	left	right	
Pre-training	33	39	14.85	14.00	80	90	145
Session 04	33	39	14.85	14.00	90	95	155
Session 08	33	39	15.60	15.50	90	100	160
Session 12	34	39	15.60	15.50	90	105	165
Session 16	35	45	17.85	18.75	100	110	180
Post-training	35	45	17.85	18.75	100	110	180

Subject C

	Handgrip (kg)		SAC (kg)		SLP (kg)		DLP (kg)
	left	right	left	right	left	right	
Pre-training	45	47	15.60	16.25	95	115	170
Session 04	46	52	20.10	25.00	95	115	180
Session 08	54	57	22.60	26.25	105	120	195
Session 12	57	58	22.60	26.25	105	120	200
Session 16	62	66	22.60	26.25	105	125	205
Post-training	62	66	22.60	26.25	105	125	205

Subject D

	Handgrip (kg)		SAC (kg)		SLP (kg)		DLP (kg)
	left	right	left	right	left	right	
Pre-training	33	33	13.35	10.25	115	110	190
Session 04	38	33	13.35	11.75	115	120	230
Session 08	39	36	13.35	13.25	140	140	250
Session 12	43	42	14.10	13.25	140	140	250
Session 16	44	43	14.50	15.50	140	140	265
Post-training	44	43	14.50	15.50	140	140	265

Subject E

	Handgrip (kg)		SAC (kg)		SLP (kg)		DLP (kg)
	left	right	left	right	left	right	
Pre-training	40	47	15.60	17.50	80.0	95.0	145.0
Session 04	43	49	15.60	21.50	80.0	95.0	145.0
Session 08	45	55	16.35	21.50	82.5	97.5	152.5
Session 12	50	60	21.35	30.00	85.0	100.0	160.0
Session 16	58	60	28.85	36.75	90.0	102.5	170.0
Post-training	58	60	28.85	36.75	90.0	102.5	170.0

Subject F

	Handgrip (kg)		SAC (kg)		SLP (kg)		DLP (kg)
	left	right	left	right	left	right	
Pre-training	49	43	14.10	14.75	80.0	90.0	160.0
Session 04	55	49	14.85	16.25	95.0	105.0	170.0
Session 08	58	50	16.35	17.50	95.0	105.0	180.0
Session 12	59	55	18.85	17.50	100.0	112.5	180.0
Session 16	65	59	26.35	17.50	105.0	115.0	190.0
Post-training	65	59	26.35	17.50	105.0	115.0	190.0

Subject G

	Handgrip (kg)		SAC (kg)		SLP (kg)		DLP (kg)
	left	right	left	right	left	right	
Pre-training	50	56	16.35	18.75	105	100	180
Session 04	50	56	23.85	35.35	115	110	200
Session 08	54	56	30.62	37.61	125	125	230
Session 12	57	56	30.62	37.61	135	140	250
Session 16	57	56	31.35	58.40	135	140	250
Post-training	57	56	31.35	58.40	135	140	250

APPENDIX D:

Raw Data

Maximal Voluntary Contraction Values

Isometric Handgrip (kg) – dominant hand

	SUBJECTS								
	A	B	C	D	E	F	G		
Session #								MEAN	± SEM
1–4	50	39	47	33	47	49	56	45.9	2.9
5–8	50	39	52	33	49	55	56	47.7	3.2
9–12	50	39	57	36	55	58	56	50.1	3.4
13–16	50	39	58	42	60	59	56	52.0	3.2
17–20	50	45	66	43	60	65	56	55.0	3.5

One Repetition Maximum Values

Single–arm curl (kg) – dominant arm

	SUBJECTS								
	A	B	C	D	E	F	G		
Session #								MEAN	± SEM
1–4	15.5	14.0	16.3	10.3	17.5	14.1	18.8	15.2	1.0
5–8	16.3	14.0	25.0	11.8	21.5	14.9	35.4	19.8	3.1
9–12	16.3	15.5	26.3	13.3	21.5	16.4	37.6	21.0	3.2
13–16	21.3	15.5	26.3	13.3	30.0	18.9	37.6	23.3	3.2
17–20	28.8	18.8	26.3	15.5	36.8	26.4	58.4	30.1	5.4

One Repetition Maximum Values (continued)

Single–leg press (kg) – dominant leg

SUBJECTS

Session #	A	B	C	D	E	F	G	MEAN	± SEM
1–4	95	90	115	110	95	90	100	99.3	3.7
5–8	100	95	115	120	95	105	110	105.7	3.7
9–12	105	100	120	140	98	105	125	113.3	5.9
13–16	120	105	120	140	100	113	140	119.7	5.9
17–20	120	110	125	140	103	115	140	121.9	5.4

Double–leg press (kg)

SUBJECTS

Session #	A	B	C	D	E	F	G	MEAN	± SEM
1–4	165	145	170	190	145	160	180	165.0	6.4
5–8	180	155	180	230	145	170	200	180.0	10.7
9–12	190	160	195	250	153	180	230	194.0	13.3
13–16	200	165	200	250	160	180	250	200.7	14.0
17–20	210	180	205	265	170	190	250	210.0	13.4

Rest (Pre–training)

SUBJECTS

	A	B	C	D	E	F	G	MEAN	± SEM
Peak Syst (mmHg)	151	163	150	162	165	203	138	161.7	7.8
Peak Diast (mmHg)	77	92	87	87	96	96	84	88.4	2.6
MAP (mmHg)	93	114	108	109	111	137	100	110.3	5.2
HR (bpm)	57	64	51	52	86	61	68	62.7	4.5
RPP (x1000)	8.6	10.4	7.7	8.4	14.2	12.4	9.4	10.2	0.9

Rest (Post–training)

SUBJECTS

	A	B	C	D	E	F	G	MEAN	± SEM
Peak Syst (mmHg)	161	158	134	161	165	199	148	160.9	7.5
Peak Diast (mmHg)	77	93	79	90	100	100	93	90.3	3.5
MAP (mmHg)	100	118	87	115	124	128	107	111.3	5.4
HR (bpm)	54	60	55	68	80	69	72	65.4	3.6
RPP (x1000)	8.7	9.5	7.4	10.9	13.2	13.7	10.7	10.6	0.9

Single–arm curl @ 70% 1 RM (Pre–training)
Peak Systolic BP

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*		
REP #								MEAN	± SEM
1	179	180	161	163	165	232	156	176.6	9.8
2	185	186	166	168	155	239	152	178.7	11.2
3	192	194	169	186	158	246	147	184.6	12.2
4	192	203	172	188	168	233	147	186.1	10.4
5	197	204	174	194	169	247	163	192.6	10.8
6	203	204	174	198	166	250	170	195.0	11.0
7	205	206	185	209	169	247	171	198.9	10.2
8	209	208	186	213	180	255	165	202.3	11.0
9	214	211	194	208	184	249	168	204.0	9.7
10	216	214	198	206	194	252	177	208.1	8.9

Single–arm curl @ 70% of original 1 RM (Post–training)

Peak Systolic BP

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*		
REP #								MEAN	± SEM
1	167	188	145	165	175	209	138	169.6	9.2
2	170	192	145	164	165	211	143	170.0	9.2
3	176	198	144	173	163	216	149	174.1	9.7
4	182	203	150	181	168	216	150	178.6	9.5
5	183	203	149	186	180	218	149	181.1	9.7
6	189	203	154	187	187	222	147	184.1	9.9
7	186	203	152	183	180	222	152	182.6	9.6
8	186	203	155	177	185	219	155	182.9	8.9
9	190	207	153	174	188	222	151	183.6	10.0
10	185	199	155	185	186	225	154	184.1	9.3

Single–arm curl @ 70% of new 1 RM (Post–training)

Peak Systolic BP

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*		
REP #								MEAN	± SEM
1	200	191	150	181	178	250	175	189.3	11.7
2	184	197	156	170	174	233	145	179.9	11.0
3	189	200	159	173	180	249	155	186.4	12.0
4	199	207	158	192	198	250	164	195.4	11.5
5	211	212	163	214	208	247	194	207.0	9.5
6	208	210	166	215	200	249	215	209.0	9.3
7	211	209	172	223	207	252	210	212.0	8.9
8	215	211	182	242	214	255	220	219.9	8.9
9	219	214	182	228	225	262	231	223.0	9.0
10	223	229	193	243	236	283	241	235.4	10.2

Single–arm curl @ 70% 1 RM (Pre–training)
Peak Diastolic BP

	SUBJECTS								
REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	86	106	99	91	89	112	94	96.7	3.6
2	90	107	103	91	85	120	91	98.1	4.7
3	97	115	102	103	90	120	87	102.0	4.6
4	98	118	106	106	97	117	92	104.9	3.8
5	102	116	105	106	94	122	108	107.6	3.5
6	104	117	106	113	91	122	101	107.7	4.0
7	102	116	112	122	93	121	100	109.4	4.2
8	106	120	115	122	100	120	115	114.0	3.1
9	110	118	114	116	102	120	112	113.1	2.3
10	109	120	122	118	112	124	106	115.9	2.6

Single–arm curl @ 70% of original 1 RM (Post–training)

Peak Diastolic BP

	SUBJECTS								
	A	B	C	D	E	F	G		
REP #								MEAN	± SEM
1	86	110	87	93	112	101	82	95.9	4.5
2	84	110	84	92	100	105	90	95.0	3.9
3	88	112	85	101	102	103	92	97.6	3.6
4	91	117	91	108	104	105	91	101.0	3.9
5	94	118	86	109	109	103	93	101.7	4.2
6	97	118	93	110	108	108	91	103.6	3.8
7	99	120	91	107	110	105	97	104.1	3.6
8	101	121	93	102	114	103	96	104.3	3.7
9	95	115	93	97	117	108	96	103.0	3.8
10	100	118	89	103	110	111	96	103.9	3.7

Single–arm curl @ 70% of new 1 RM (Post–training)

Peak Diastolic BP

	SUBJECTS								
REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	117	112	96	98	111	129	115	111.1	4.3
2	110	115	100	96	119	123	99	108.9	4.0
3	115	131	101	116	120	139	116	119.7	4.6
4	114	135	99	127	120	129	114	119.7	4.5
5	130	137	102	126	127	123	120	123.6	4.1
6	126	131	102	134	120	126	152	127.3	5.7
7	129	132	108	131	138	129	144	130.1	4.2
8	132	130	115	148	139	129	151	134.9	4.7
9	135	144	118	149	145	140	158	141.3	4.7
10	138	138	126	151	150	140	165	144.0	4.7

Single–arm curl @ 70% 1RM (Pre–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	130	145	134	138	107	174	118	135.1	8.1
HR (bpm)	79	71	67	70	83	75	82	75.3	2.4

Single–arm curl @ 70% of original 1 RM (Post–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	123	148	113	131	128	144	111	128.3	5.4
HR (bpm)	68	71	63	73	79	76	76	72.3	2.1

Single–arm curl @ 70% of new 1 RM (Post–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	127	155	127	149	149	165	121	141.9	6.3
HR (bpm)	73	79	76	77	94	91	84	82.0	3.0

Single–arm curl @ 70% 1 RM (Pre–training)
Heart Rate

	SUBJECTS								
	A	B	C	D	E	F	G		
REP #								MEAN	± SEM
1	75.0	70.6	52.9	66.7	75.0	68.2	75.0	69.1	3.0
2	75.0	63.2	70.6	52.9	88.2	75.0	83.3	72.6	4.5
3	78.9	75.0	70.6	70.1	80.0	75.0	78.9	75.5	1.5
4	75.0	75.0	56.2	52.9	93.8	66.7	83.3	71.8	5.5
5	75.0	66.7	66.7	70.1	75.0	75.0	85.7	73.5	2.5
6	83.3	75.0	65.2	80.0	83.3	75.0	83.3	77.9	2.5
7	78.9	63.2	75.0	88.2	75.0	75.0	78.9	76.3	2.8
8	78.9	70.6	63.2	78.9	88.2	83.3	94.7	79.7	4.0
9	88.2	75.0	71.4	66.7	78.9	78.9	75.0	76.3	2.6
10	94.7	85.7	75.0	75.0	100.0	80.0	80.0	84.3	3.7

Single–arm curl @ 70% of original 1 RM (Post–training)

Heart Rate

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*		
REP #								MEAN	± SEM
1	60.0	71.4	63.2	60.0	75.0	75.0	83.3	69.7	3.4
2	66.7	71.4	57.1	70.6	80.0	75.0	75.0	70.8	2.8
3	63.2	66.7	57.1	70.6	80.0	70.6	75.0	69.0	2.9
4	75.0	70.6	68.2	70.6	80.0	64.3	83.3	73.1	2.5
5	63.2	63.2	57.1	75.0	80.0	75.0	63.2	68.1	3.2
6	70.6	75.0	63.2	75.0	69.2	70.6	83.3	72.4	2.4
7	70.6	66.7	65.2	78.9	75.0	75.0	66.7	71.2	2.0
8	70.6	75.0	60.0	75.0	80.0	80.0	83.3	74.8	2.9
9	70.6	75.0	75.0	71.4	85.7	75.0	78.9	75.9	1.9
10	69.2	81.8	62.5	78.9	81.8	85.7	70.6	75.8	3.2

Single–arm curl @ 70% of new 1 RM (Post–training)

Heart Rate

SUBJECTS

REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	63.2	75.0	71.4	64.3	69.2	80.0	72.0	70.7	2.2
2	75.0	75.0	63.2	60.0	92.3	85.7	90.0	77.3	4.8
3	75.0	80.0	78.9	78.9	100.0	90.0	81.8	83.5	3.3
4	75.0	75.0	71.4	70.6	80.0	90.0	91.3	79.0	3.2
5	81.8	115.4	75.0	70.6	100.0	78.9	78.3	85.7	6.1
6	85.2	75.0	78.9	88.2	80.0	95.5	90.0	84.7	2.7
7	88.9	75.0	78.9	75.0	107.1	90.0	90.3	86.5	4.3
8	92.6	85.7	78.3	90.0	85.7	95.5	92.2	88.6	2.2
9	96.3	80.0	81.8	88.2	112.5	95.5	94.0	92.6	4.1
10	100.0	92.3	81.8	80.0	109.1	105.0	95.9	94.9	4.2

Single–arm curl @ 70% 1 RM (Pre–training)
Rate Pressure Product

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*		
REP #								MEAN	± SEM
1	13.4	12.7	8.5	10.9	12.4	15.8	11.7	12.2	0.8
2	13.9	11.8	11.7	8.9	13.7	17.9	12.7	12.9	1.0
3	15.1	14.6	11.9	13.0	12.6	18.5	11.6	13.9	0.9
4	14.4	15.2	9.7	9.9	15.8	15.5	12.2	13.2	1.0
5	14.8	13.6	11.6	13.6	12.7	18.5	14.0	14.1	0.8
6	16.9	15.3	11.3	15.8	13.8	18.8	14.2	15.2	0.9
7	16.2	13.0	13.9	18.4	12.7	18.5	13.5	15.2	0.9
8	16.5	14.7	11.8	16.8	15.9	21.2	15.6	16.1	1.1
9	18.9	15.8	13.9	13.9	14.5	19.7	12.6	15.6	1.0
10	20.5	18.3	14.9	15.5	19.4	20.2	14.2	17.6	1.0

Single–arm curl @ 70% of original 1 RM (Post–training)

Rate Pressure Product

REP #	SUBJECTS A	B	C	D	E	F	G	MEAN	± SEM
1	10.0	13.4	9.2	9.9	13.1	15.7	11.5	11.8	0.9
2	11.3	13.7	8.3	11.6	13.2	15.8	10.7	12.1	0.9
3	11.1	13.2	8.2	12.2	13.0	15.2	11.2	12.0	0.8
4	13.7	14.3	10.2	12.8	13.4	13.9	12.5	13.0	0.5
5	11.6	12.8	8.5	14.0	14.4	16.4	9.4	12.4	1.1
6	13.3	15.2	9.7	14.0	12.9	15.7	12.2	13.3	0.8
7	13.1	13.5	9.9	14.4	13.5	16.7	10.1	13.0	0.9
8	13.1	15.2	9.3	13.3	14.8	17.5	12.9	13.7	1.0
9	13.4	15.5	11.5	12.4	16.1	16.7	11.9	13.9	0.8
10	12.8	16.3	9.7	14.6	15.2	19.3	10.9	14.1	1.2

Single–arm curl @ 70% of new 1 RM (Post–training)

Rate Pressure Product

REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	12.6	14.3	10.7	11.6	12.3	20.0	12.6	13.4	1.2
2	13.8	14.8	9.9	10.2	16.1	20.0	13.1	14.0	1.3
3	14.2	16.0	12.5	13.6	18.0	22.4	12.7	15.6	1.3
4	14.9	15.5	11.3	13.6	15.8	22.5	15.0	15.5	1.3
5	17.3	24.5	12.2	15.1	20.8	19.5	15.2	17.8	1.6
6	17.7	15.7	13.1	19.0	16.0	23.8	19.4	17.8	1.3
7	18.8	15.7	13.6	16.7	22.2	22.7	18.9	18.4	1.3
8	19.8	18.1	14.3	21.8	18.3	24.4	20.1	19.5	1.2
9	20.9	17.1	14.9	20.1	25.3	25.0	21.4	20.7	1.4
10	21.9	21.1	15.8	19.4	25.7	29.7	22.6	22.3	1.7

Columns A–G are under the heading SUBJECTS.

Single–leg press @ 80% 1 RM (Pre–training)

Peak Systolic BP

	SUBJECTS								
REP #	*A*	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
1	185	180	179	184	198	232	165	189.0	8.1
2	193	189	166	175	191	239	161	187.7	9.8
3	196	205	165	187	202	256	160	195.9	12.0
4	192	222	171	192	203	245	162	198.1	10.8
5	198	218	174	201	209	251	162	201.9	11.0
6	199	218	174	208	212	252	167	204.3	10.8
7	199	230	194	210	214	247	170	209.1	9.5
8	198	227	193	202	222	258	169	209.9	10.8
9	203	234	193	198	233	258	172	213.0	11.2
10	201	245	197	207	242	268	174	219.1	12.5
11	203	236	209	206	258	264	173	221.3	12.4
12	204	240	212	213	271	281	186	229.6	13.5

Single–leg press @ 80% of original 1 RM (Post–training)

Peak Systolic BP

	SUBJECTS								
REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	179	190	145	176	220	219	154	183.3	11.0
2	178	190	141	176	186	223	156	178.6	9.9
3	180	210	146	184	198	225	155	185.4	10.7
4	180	208	156	194	216	221	158	190.4	10.1
5	178	208	161	191	212	218	163	190.1	8.9
6	177	212	166	193	228	223	167	195.1	9.9
7	175	215	160	194	225	228	162	194.1	11.0
8	183	217	170	199	225	228	164	198.0	9.9
9	186	223	174	207	234	230	168	203.1	10.3
10	187	212	170	212	245	235	166	203.9	11.6
11	188	218	187	218	254	238	169	210.3	11.5
12	188	228	179	228	240	240	169	210.3	11.5

Single–leg press @ 80% of new 1 RM (Post–training)

Peak Systolic BP

REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	175	200	146	195	270	228	165	197.0	15.7
2	173	217	149	187	236	228	154	192.0	13.4
3	175	233	155	198	216	230	148	193.6	13.2
4	174	232	158	204	218	233	158	196.7	12.5
5	182	233	162	209	227	234	169	202.3	11.7
6	185	242	166	220	243	245	169	210.0	13.5
7	187	243	176	225	251	251	172	215.0	13.5
8	184	244	182	219	252	254	179	216.3	13.0
9	182	252	189	227	257	263	168	219.7	15.0
10	187	253	190	234	281	264	186	227.9	15.2
11	191	264	191	245	286	276	197	235.7	15.8
12	195	268	198	252	313	286	223	247.9	16.9

Columns A–G are headed "SUBJECTS".

Single–leg press @ 80% 1 RM (Pre–training)
Peak Diastolic BP

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*		
REP #								MEAN	± SEM
1	94	112	98	102	117	132	97	107.4	5.2
2	96	115	96	98	118	130	100	107.6	5.1
3	99	124	103	97	114	129	94	108.6	5.2
4	98	127	104	105	115	132	95	110.9	5.4
5	100	138	104	108	126	130	97	114.7	6.2
6	98	136	106	115	127	110	103	113.6	5.1
7	100	128	119	109	122	135	102	116.4	5.0
8	99	144	118	112	133	136	101	120.4	6.7
9	99	152	113	103	136	117	104	117.7	7.4
10	97	147	126	114	150	138	102	124.9	8.0
11	99	155	134	115	138	127	106	124.9	7.4
12	99	157	130	122	158	127	105	128.3	8.7

Single–leg press @ 80% of original 1 RM (Post–training)

Peak Diastolic BP

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*		
REP #								MEAN	± SEM
1	92	125	84	92	114	110	88	100.7	5.9
2	91	119	82	105	118	102	89	100.9	5.4
3	92	131	90	114	120	103	90	105.7	6.2
4	92	132	94	116	134	100	93	108.7	7.0
5	92	136	97	114	128	98	97	108.9	6.6
6	89	140	96	117	133	105	95	110.7	7.5
7	90	133	96	120	126	106	96	109.6	6.3
8	93	134	102	123	126	102	98	111.1	6.1
9	94	132	102	127	129	107	97	112.6	6.1
10	96	129	104	138	137	111	96	115.9	7.0
11	94	137	120	151	156	114	99	124.4	9.2
12	95	139	113	146	140	115	97	120.7	8.0

Single–leg press @ 80% of new 1 RM (Post–training)

Peak Diastolic BP

	SUBJECTS								
REP #	*A*	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
1	92	128	80	114	130	115	114	110.4	6.9
2	93	144	88	107	119	123	89	109.0	7.9
3	94	146	90	114	131	125	93	113.3	8.2
4	93	158	92	119	141	118	100	117.3	9.5
5	101	164	96	130	130	148	109	125.4	9.5
6	106	160	99	129	163	149	114	131.4	9.9
7	101	180	108	125	142	133	105	127.7	10.5
8	102	178	111	131	150	139	114	132.1	9.9
9	108	177	112	138	158	147	110	135.7	10.1
10	106	178	113	138	173	151	131	141.4	10.5
11	109	181	126	148	192	137	130	146.1	11.4
12	108	173	112	143	194	150	139	145.6	11.7

Single–leg press @ 80% 1RM (Pre–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	134	155	136	140	131	175	117	141.1	7.1
HR (bpm)	76	82	79	71	90	83	80	80.1	2.2

Single–leg press @ 80% of original 1 RM (Post–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	125	162	118	152	160	136	118	138.7	7.3
HR (bpm)	62	78	78	78	96	76	76	77.7	3.7

Single–leg press @ 80% of new 1 RM (Post–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	132	179	121	160	179	157	124	150.3	9.3
HR (bpm)	69	85	82	85	107	92	83	86.1	4.3

Single–leg press @ 80% 1 RM (Pre–training)
Heart Rate

	SUBJECTS								
	A	B	C	D	E	F	G		
REP #								MEAN	± SEM
1	66.7	71.4	56.2	54.5	78.9	75.0	75.0	68.2	3.6
2	75.0	75.0	70.6	57.1	90.0	85.7	75.0	75.5	4.0
3	88.2	75.0	64.3	72.0	81.8	75.0	75.0	75.9	2.8
4	75.0	75.0	81.8	75.0	95.5	75.0	78.9	79.5	2.9
5	88.2	85.7	75.0	68.2	95.5	78.9	78.9	81.5	3.4
6	88.2	75.0	80.0	66.7	100.0	78.9	78.9	81.1	4.0
7	75.0	78.9	83.3	75.0	116.7	81.8	85.7	85.2	5.5
8	88.2	85.7	83.3	81.8	94.7	85.7	78.9	85.5	1.9
9	80.0	90.0	75.0	75.0	110.5	78.9	90.0	85.6	4.8
10	93.7	90.0	100.0	75.0	110.5	91.3	75.0	90.8	4.8
11	85.7	87.5	83.3	88.2	100.0	90.0	90.0	89.2	2.0
12	80.0	90.0	100.0	66.7	112.5	94.7	88.2	90.3	5.5

Single–leg press @ 80% of original 1 RM (Post–training)
Heart Rate

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*		
REP #								MEAN	± SEM
1	56.3	70.6	66.7	56.2	78.9	78.9	75.0	68.9	3.7
2	64.3	64.3	78.9	66.7	88.2	88.2	75.0	75.1	4.0
3	66.7	83.3	66.7	75.0	94.7	75.0	75.0	76.6	3.7
4	52.9	75.0	78.9	83.3	100.0	80.0	66.7	76.7	5.5
5	75.0	70.6	78.9	75.0	90.0	70.6	78.9	77.0	2.5
6	56.3	80.0	75.0	83.3	88.2	83.3	70.6	76.7	4.0
7	52.9	75.0	75.0	70.6	100.0	83.3	83.3	77.2	5.4
8	75.0	88.2	83.3	83.3	100.0	70.6	75.0	82.2	3.8
9	56.3	80.0	78.9	78.9	105.9	78.9	78.9	79.7	5.4
10	60.0	80.0	78.9	85.7	94.7	88.2	78.9	80.9	4.1
11	75.0	88.2	81.8	85.7	116.7	83.3	75.0	86.5	5.4
12	60.0	85.7	85.7	92.3	105.9	83.3	75.0	84.0	5.4

Single–leg press @ 80% of new 1 RM (Post–training)

Heart Rate

REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	70.6	70.6	78.9	64.3	92.3	78.9	83.3	77.0	3.5
2	60.0	75.0	75.0	75.0	100.0	88.2	60.0	76.2	5.4
3	69.2	83.3	66.7	83.3	105.9	83.3	75.0	81.0	4.9
4	66.7	80.0	81.8	70.6	90.0	83.3	83.3	79.4	3.0
5	63.2	78.9	66.7	83.3	100.0	94.7	83.3	81.4	5.1
6	70.6	88.2	83.3	88.3	105.0	94.7	83.3	87.6	4.0
7	64.3	83.3	90.0	88.3	105.9	88.2	83.3	86.2	4.6
8	69.2	88.2	83.3	88.3	112.5	94.7	90.0	89.5	4.9
9	70.6	88.2	88.2	94.7	110.5	94.7	88.2	90.7	4.5
10	80.0	88.2	83.3	88.3	116.7	105.0	85.7	92.5	5.0
11	64.3	88.2	90.0	93.7	120.0	94.7	90.0	91.6	6.1
12	75.0	100.0	94.7	90.0	120.0	100.0	88.2	95.4	5.2

Single–leg press @ 80% 1 RM (Pre–training)
Rate Pressure Product

SUBJECTS

REP #	*A*	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
1	12.3	12.9	10.1	10.0	15.6	17.4	12.4	13.0	1.0
2	14.5	14.2	11.7	10.0	17.2	20.5	12.1	14.3	1.4
3	17.3	15.4	10.6	13.5	16.5	19.2	12.0	14.9	1.2
4	14.4	16.7	14.0	14.4	19.4	18.4	12.8	15.7	0.9
5	17.5	18.7	13.1	13.7	20.0	19.8	12.8	16.5	1.2
6	17.6	16.4	13.9	13.9	21.2	19.9	13.2	16.6	1.2
7	14.9	18.1	16.2	15.8	25.0	20.2	14.6	17.8	1.4
8	17.5	19.5	16.1	16.5	21.0	22.1	13.3	18.0	1.2
9	16.2	21.1	14.5	14.9	25.7	20.4	15.5	18.3	1.6
10	18.8	22.1	19.7	15.5	26.7	24.5	13.1	20.1	1.8
11	17.4	20.7	17.4	18.2	25.8	23.8	15.6	19.8	1.4
12	16.3	21.6	21.2	14.2	30.5	26.6	16.4	21.0	2.2

Single–leg press @ 80% of original 1 RM (Post–training)

Rate Pressure Product

REP #	SUBJECTS A	B	C	D	E	F	G	MEAN	± SEM
1	10.1	13.4	9.7	9.9	17.4	17.3	11.6	12.8	1.3
2	11.4	12.2	11.1	11.7	16.4	19.7	11.7	13.5	1.2
3	12.0	17.5	9.7	13.8	18.8	16.9	11.6	14.3	1.3
4	9.5	15.6	12.3	16.2	21.6	17.7	10.5	14.8	1.6
5	13.4	14.7	12.7	14.3	19.1	15.4	12.9	14.6	0.8
6	10.0	17.0	12.5	16.1	20.1	18.6	11.8	15.2	1.4
7	9.3	16.1	12.0	13.7	22.5	19.0	13.5	15.2	1.7
8	13.7	19.1	14.1	16.6	22.5	16.1	12.3	16.3	1.3
9	10.5	17.8	13.7	16.3	24.8	18.1	13.3	16.4	1.7
10	11.2	17.0	13.4	18.2	23.2	20.7	13.1	16.7	1.7
11	14.1	19.2	15.3	18.7	29.6	19.8	12.7	18.5	2.1
12	11.3	19.5	15.3	21.0	25.4	20.0	12.7	17.9	1.9

Single–leg press @ 80% of new 1 RM (Post–training)

Rate Pressure Product

SUBJECTS

REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	12.4	14.1	11.5	12.5	24.9	18.0	13.7	15.3	1.8
2	10.4	16.3	11.2	14.0	23.6	20.1	9.2	15.0	2.0
3	12.1	19.4	10.3	16.5	22.9	19.2	11.1	15.9	1.8
4	11.6	18.6	12.9	14.4	19.6	19.4	13.2	15.7	1.3
5	11.5	18.4	10.8	17.4	22.7	22.2	14.1	16.7	1.8
6	13.1	21.3	13.8	19.4	25.5	23.2	14.1	18.6	1.9
7	12.0	20.2	15.8	19.9	26.6	22.1	14.3	18.7	1.9
8	12.7	21.5	15.2	19.3	28.4	24.1	16.1	19.6	2.1
9	12.8	22.2	16.7	21.5	28.4	24.9	14.8	20.2	2.1
10	15.0	22.3	15.8	20.7	32.8	27.7	16.0	21.5	2.5
11	12.3	23.3	17.2	23.0	34.3	26.1	17.7	22.0	2.7
12	14.6	26.8	18.8	22.7	37.6	28.6	19.7	24.1	2.9

Double–leg press @ 80% 1 RM (Pre–training)

Peak Systolic BP

	SUBJECTS								
REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	183	194	172	211	234	238	159	198.7	11.4
2	186	208	167	184	210	245	158	194.0	11.2
3	192	213	175	195	212	262	164	201.9	12.1
4	193	221	180	200	211	248	170	203.3	9.9
5	191	219	181	199	238	247	174	207.0	10.7
6	192	227	189	205	236	254	174	211.0	10.9
7	198	232	191	212	228	255	179	213.6	10.0
8	198	232	193	212	240	254	181	215.7	10.2
9	204	228	200	212	244	260	185	219.0	10.0
10	210	234	200	221	234	265	185	221.3	9.9
11	212	243	201	230	240	272	192	227.1	10.4
12	217	248	201	235	249	276	194	231.4	11.0

Double–leg press @ 80% of original 1 RM (Post–training)

Peak Systolic BP

	SUBJECTS								
	A	B	C	D	E	F	G		
REP #								MEAN	± SEM
1	178	204	155	217	216	237	166	196.1	11.4
2	181	207	150	207	188	224	167	189.1	9.7
3	179	220	161	217	203	224	168	196.0	9.9
4	180	222	168	210	209	226	168	197.6	9.4
5	181	222	168	219	214	227	174	200.7	9.5
6	182	223	166	231	206	235	173	202.3	10.8
7	183	218	168	236	211	239	174	204.1	11.1
8	187	222	176	230	216	243	173	206.7	10.5
9	191	232	180	229	216	247	176	210.1	10.5
10	192	231	187	237	229	251	180	215.3	10.7
11	197	234	188	238	229	251	179	216.6	10.6
12	198	242	184	256	224	253	182	219.9	12.1

Double–leg press @ 80% of new 1 RM (Post–training)

Peak Systolic BP

	SUBJECTS								
REP #	*A*	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
1	182	211	161	215	216	232	159	196.6	11.0
2	184	213	160	221	203	234	166	197.3	10.6
3	186	234	162	230	208	236	183	205.6	11.0
4	186	240	171	240	203	240	164	206.3	12.8
5	192	244	175	254	224	250	186	217.9	12.5
6	189	252	180	263	223	255	194	222.3	13.2
7	194	257	187	287	234	258	197	230.6	14.6
8	201	264	193	287	230	264	203	234.6	14.1
9	203	269	199	286	233	269	209	238.3	13.7
10	206	268	200	318	227	271	215	243.6	16.4
11	210	267	212	319	240	272	222	248.9	15.0
12	213	281	217	336	249	278	228	257.4	16.7

Double–leg press @ 80% 1 RM (Pre–training)
Peak Diastolic BP

	SUBJECTS								
REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	92	113	109	119	116	133	93	110.7	5.5
2	101	120	97	101	124	131	97	110.1	5.4
3	97	123	102	111	112	121	99	109.3	3.9
4	100	126	109	115	120	120	105	113.6	3.5
5	102	131	110	119	126	127	105	117.1	4.4
6	102	132	111	114	126	134	109	118.3	4.7
7	101	130	116	118	128	139	118	121.4	4.6
8	100	137	110	115	123	126	110	117.3	4.6
9	110	140	121	122	124	145	110	124.6	5.1
10	111	143	114	124	122	129	113	122.3	4.3
11	119	148	119	129	127	126	114	126.0	4.2
12	114	139	120	138	140	150	109	130.0	5.9

Double–leg press @ 80% of original 1 RM (Post–training)

Peak Diastolic BP

	SUBJECTS								
	A	B	C	D	E	F	G		
REP #								MEAN	± SEM
1	94	127	86	116	115	108	97	106.1	5.5
2	92	130	82	114	104	108	95	103.6	6.0
3	96	134	92	121	117	111	99	110.0	5.7
4	99	136	92	116	118	107	101	109.9	5.6
5	98	133	91	120	119	110	104	110.7	5.4
6	98	133	88	131	119	121	106	113.7	6.4
7	100	132	92	130	114	115	104	112.4	5.7
8	103	138	98	133	120	115	102	115.6	5.9
9	109	143	102	136	120	123	106	119.9	5.8
10	108	143	104	132	122	121	107	119.6	5.4
11	111	140	103	143	124	121	109	121.6	5.8
12	111	142	100	145	117	118	107	120.0	6.5

Double–leg press @ 80% of new 1 RM (Post–training)

Peak Diastolic BP

	SUBJECTS								
	A	B	C	D	E	F	G		
REP #								MEAN	± SEM
1	95	132	92	124	132	118	112	115.0	6.2
2	99	142	88	126	107	115	107	112.0	6.7
3	96	158	98	138	113	117	114	119.1	8.3
4	101	163	103	145	133	123	113	125.9	8.6
5	103	154	102	168	131	140	139	133.9	9.3
6	108	176	106	179	124	142	95	132.9	12.8
7	112	176	118	155	132	140	114	135.3	9.0
8	117	174	118	162	135	136	115	136.7	8.8
9	121	175	114	196	129	132	115	140.3	12.2
10	120	182	122	195	129	139	115	143.1	12.1
11	126	193	112	205	143	137	116	147.4	14.0
12	121	172	120	201	124	128	116	140.3	12.4

Double–leg press @ 80% 1RM
(Pre–training)

SUBJECTS

	A	B	C	D	E	F	G	MEAN	± SEM
MAP (mmHg)	132	158	129	145	150	173	122	144.1	6.8
HR (bpm)	85	83	81	75	99	94	85	86.0	3.0

Double–leg press @ 80% of original 1 RM
(Post–training)

SUBJECTS

	A	B	C	D	E	F	G	MEAN	± SEM
MAP (mmHg)	131	162	115	156	158	151	124	142.4	7.1
HR (bpm)	68	82	82	82	103	91	84	84.6	4.0

Double–leg press @ 80% of new 1 RM
(Post–training)

SUBJECTS

	A	B	C	D	E	F	G	MEAN	± SEM
MAP (mmHg)	141	185	122	180	167	164	122	154.4	9.9
HR (bpm)	77	92	91	92	109	100	89	92.9	3.7

Double–leg press @ 80% 1 RM (Pre–training)
Heart Rate

SUBJECTS

REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	66.7	68.2	75.0	62.5	90.0	83.3	71.4	73.9	3.7
2	83.3	71.4	66.7	50.0	88.2	78.9	83.3	74.5	5.0
3	75.0	81.8	83.3	78.9	90.0	90.0	83.3	83.2	2.1
4	83.3	81.8	71.4	66.7	93.7	88.2	90.0	82.2	3.7
5	83.3	80.8	85.7	81.8	105.0	88.2	78.9	86.2	3.3
6	94.7	84.0	78.9	75.0	100.0	94.7	88.2	87.9	3.5
7	88.2	85.7	83.3	78.3	112.5	94.7	85.7	89.8	4.2
8	80.0	90.0	80.0	70.6	100.0	93.7	90.0	86.3	3.8
9	94.7	90.0	90.0	83.3	88.2	95.5	90.0	90.2	1.5
10	88.2	87.5	80.0	94.7	109.1	105.0	83.3	92.5	4.1
11	88.2	94.7	88.2	78.9	94.7	105.9	94.7	92.2	3.1
12	94.7	88.2	94.7	80.0	109.1	105.9	88.2	94.4	3.9

Double–leg press @ 80% of original 1 RM (Post–training)

Heart Rate

	SUBJECTS								
	A	B	C	D	E	F	G		
REP #								MEAN	± SEM
1	50.0	66.7	71.4	75.0	93.8	100.0	75.0	76.0	6.3
2	66.7	80.0	75.0	75.0	88.2	75.0	75.0	76.4	2.5
3	66.7	75.0	75.0	70.6	112.5	90.0	80.0	81.4	5.9
4	63.2	80.0	78.9	75.0	100.0	88.2	83.3	81.2	4.3
5	78.9	83.3	78.9	83.3	100.0	83.3	83.3	84.4	2.7
6	66.7	83.3	78.9	83.3	100.0	94.7	83.3	84.3	4.1
7	60.0	83.3	83.3	83.3	100.0	88.2	83.3	83.1	4.5
8	70.6	78.9	90.0	75.0	105.9	93.7	78.9	84.7	4.7
9	75.0	88.2	75.0	90.0	105.9	94.7	93.7	88.9	4.2
10	70.6	83.3	85.7	88.2	112.5	94.7	94.7	90.0	4.9
11	70.6	88.2	94.7	88.2	105.9	88.2	83.3	88.4	4.0
12	78.9	90.0	94.7	93.7	120.0	94.7	94.7	95.2	4.7

Double–leg press @ 80% of new 1 RM (Post–training)

Heart Rate

	SUBJECTS								
	A	B	C	D	E	F	G		
REP #								MEAN	± SEM
1	52.9	83.3	78.9	75.0	100.0	83.3	83.3	79.5	5.3
2	70.6	70.6	78.9	75.0	100.0	88.2	83.3	80.9	4.0
3	66.7	83.3	78.9	90.0	100.0	94.7	90.0	86.2	4.2
4	70.6	88.2	90.0	81.8	105.9	100.0	88.2	89.2	4.4
5	70.6	88.2	83.3	91.3	100.0	100.0	92.3	89.4	3.9
6	83.3	90.0	90.0	90.0	112.5	100.0	95.5	94.5	3.6
7	70.6	100.0	94.7	90.0	105.0	105.9	97.4	94.8	4.6
8	78.9	90.0	94.7	100.0	110.5	105.0	99.9	97.0	3.9
9	83.3	100.0	100.0	96.4	116.7	93.8	102.3	98.9	3.8
10	88.2	100.0	105.0	100.0	110.5	116.7	104.8	103.6	3.4
11	88.2	100.0	100.0	100.0	114.3	100.0	107.2	101.4	3.0
12	90.0	110.5	100.0	104.3	123.6	112.5	109.7	107.2	4.0

Double–leg press @ 80% 1 RM (Pre–training)

Rate Pressure Product

	SUBJECTS								
REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	12.2	13.2	12.9	13.2	21.1	19.8	11.4	14.8	1.5
2	15.5	14.9	11.1	9.2	18.5	19.3	13.2	14.5	1.4
3	14.4	17.4	14.6	15.4	19.1	23.6	13.7	16.9	1.3
4	16.1	18.1	12.9	13.3	19.8	21.9	15.3	16.8	1.3
5	15.9	17.7	15.5	16.3	25.0	21.8	13.7	18.0	1.5
6	18.2	19.1	14.9	15.4	23.6	24.1	15.3	18.7	1.5
7	17.5	19.9	15.9	16.6	25.7	24.0	15.3	19.3	1.6
8	15.8	20.1	15.4	15.0	24.0	23.8	16.3	18.6	1.5
9	19.3	20.5	18.0	17.7	21.5	24.8	16.7	19.8	1.0
10	18.5	20.5	16.0	20.9	25.5	27.8	15.4	20.7	1.7
11	18.7	23.0	17.7	18.1	22.7	28.8	18.2	21.0	1.5
12	20.5	21.9	19.0	18.8	27.2	29.2	17.1	22.0	1.7

Double–leg press @ 80% of original 1 RM (Post–training)

Rate Pressure Product

	SUBJECTS								
REP #	*A*	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
1	8.9	13.6	11.1	16.3	20.3	23.7	12.5	15.2	2.0
2	12.1	16.6	11.3	15.5	16.6	16.8	12.5	14.5	0.9
3	11.9	16.5	12.1	15.3	22.8	20.2	13.4	16.0	1.6
4	11.4	17.8	13.3	15.8	20.9	19.9	14.0	16.2	1.3
5	14.3	18.5	13.3	18.2	21.4	18.9	14.5	17.0	1.1
6	12.1	18.6	13.1	19.2	20.6	22.3	14.4	17.2	1.5
7	11.0	18.2	14.0	19.7	21.1	21.1	14.5	17.1	1.5
8	13.2	17.5	15.8	17.3	22.9	22.8	13.6	17.6	1.5
9	14.3	20.5	13.5	20.6	22.9	23.4	16.5	18.8	1.5
10	13.6	19.2	16.0	20.9	25.8	23.8	17.0	19.5	1.6
11	13.9	20.6	17.8	21.0	24.3	22.1	14.9	19.2	1.4
12	15.6	21.8	17.4	24.0	26.9	24.0	17.2	21.0	1.6

Double–leg press @ 80% of new 1 RM (Post–training)

Rate Pressure Product

SUBJECTS

REP #	A	B	C	D	E	F	G	MEAN	± SEM
1	9.6	17.6	12.7	16.1	21.6	19.3	13.2	15.7	1.6
2	13.0	15.0	12.6	16.6	20.3	20.6	13.8	16.0	1.3
3	12.4	19.5	12.8	20.7	20.8	22.3	16.5	17.9	1.5
4	13.1	21.2	15.4	19.6	21.5	24.0	14.5	18.5	1.6
5	13.6	21.5	14.6	23.2	22.4	25.0	17.2	19.6	1.7
6	15.7	22.7	16.2	23.7	25.1	25.5	18.5	21.1	1.6
7	13.7	25.7	17.7	25.8	24.6	27.3	19.1	22.0	1.9
8	15.9	23.8	18.3	28.7	25.4	27.7	20.1	22.8	1.8
9	16.9	26.9	19.9	27.6	27.2	25.2	21.1	23.5	1.6
10	18.2	26.8	21.0	31.8	25.1	31.6	22.1	25.2	2.0
11	18.5	26.7	21.2	31.9	27.4	27.2	23.0	25.1	1.7
12	19.2	31.1	21.7	35.0	30.8	31.3	24.0	27.6	2.2

Isometric Handgrip @ 50% MVC (Pre–training)

SUBJECTS

	A	B	C	D	E	F	G	MEAN	± SEM
Peak Syst (mmHg)	187	197	198	213	173	246	164	196.9	10.3
Peak Diast (mmHg)	93	111	110	105	101	112	102	104.9	2.6
MAP (mmHg)	116	136	129	133	116	152	108	127.1	5.7
HR (bpm)	70	66	72	62	79	78	80	72.4	2.6
RPP (x1000)	13.1	13.0	14.3	13.2	13.7	19.2	13.1	14.2	0.8

Isometric Handgrip @ 50% of original MVC (Post–training)

SUBJECTS

	A	B	C	D	E	F	G	MEAN	± SEM
Peak Syst (mmHg)	174	197	148	197	190	241	169	188.0	11.1
Peak Diast (mmHg)	84	111	81	102	112	109	97	99.4	4.8
MAP (mmHg)	115	137	99	133	132	147	78	120.1	9.2
HR (bpm)	54	66	62	74	90	76	86	72.6	4.9
RPP (x1000)	9.4	13.0	9.2	14.6	17.1	18.3	14.5	13.7	1.3

Isometric Handgrip @ 50% of new MVC (Post–training)

SUBJECTS

	A	B	C	D	E	F	G	MEAN	± SEM
Peak Syst (mmHg)	175	197	155	217	191	246	169	192.9	11.7
Peak Diast (mmHg)	89	119	90	125	115	122	97	108.1	5.9
MAP (mmHg)	119	143	104	140	137	149	78	124.3	9.7
HR (bpm)	58	70	68	76	86	82	86	75.1	3.9
RPP (x1000)	10.2	13.8	10.5	16.5	16.4	20.2	14.5	14.6	1.3

Treadmill (Pre–training) – Peak Systolic BP

SUBJECTS

time (min)	A	B	C	D	E	F	G	MEAN	± SEM
0–1	189	166	148	203	218	248	169	191.6	13.0
1–2	190	170	166	222	221	253	173	199.3	12.6
2–3	188	176	166	258	222	248	177	205.0	14.1
3–4	202	182	155	252	221	243	172	203.9	13.8
4–5	201	186	158	253	210	246	172	203.7	13.5
5–6	199	166	156	265	212	239	167	200.6	15.5
6–7	194	167	156	268	211	239	167	200.3	15.7
7–8	196	173	150	271	204	238	168	200.0	16.0
8–9	201	180	154	260	210	239	177	203.0	14.0
9–10	202	168	153	263	215	243	170	202.0	15.5

Treadmill (Post–training)

SUBJECTS

time (min)	A	B	C	D	E	F	G	MEAN	± SEM
0–1	167	173	131	216	202	228	161	182.6	12.9
1–2	164	163	135	233	203	225	171	184.9	13.7
2–3	168	163	136	246	198	224	170	186.4	14.5
3–4	173	172	141	249	199	223	165	188.9	14.0
4–5	169	170	138	262	208	232	177	193.7	16.1
5–6	172	163	130	272	209	241	170	193.9	18.7
6–7	172	167	138	259	205	234	167	191.7	16.2
7–8	164	164	153	259	201	222	169	190.3	14.7
8–9	174	173	141	282	217	224	166	196.7	18.0
9–10	178	176	137	272	216	231	176	198.0	16.9

Treadmill (Pre–training) – Peak Diastolic BP

time (min)	A	B	C	D	E	F	G	MEAN	± SEM
0–1	80	95	72	96	100	108	84	90.7	4.7
1–2	82	86	87	105	102	97	92	93.0	3.3
2–3	78	84	80	121	106	95	91	93.6	5.8
3–4	85	94	78	115	101	96	89	94.0	4.5
4–5	87	106	77	117	100	102	88	96.7	5.1
5–6	82	84	77	141	100	100	88	96.0	8.2
6–7	80	84	75	138	95	101	86	94.1	8.0
7–8	80	87	72	130	94	97	89	92.7	7.0
8–9	84	90	78	134	98	107	88	97.0	7.1
9–10	84	87	75	122	102	103	90	94.7	5.9

Treadmill (Post–training)

time (min)	A	B	C	D	E	F	G	MEAN	± SEM
0–1	75	100	54	104	102	93	84	87.4	6.8
1–2	74	88	59	108	97	95	90	87.3	6.1
2–3	75	87	54	113	98	97	84	86.9	7.1
3–4	78	92	58	113	100	97	88	89.4	6.6
4–5	79	90	59	126	102	99	87	91.7	7.9
5–6	76	86	59	122	106	105	87	91.6	8.0
6–7	75	87	54	118	108	100	83	89.3	8.1
7–8	72	89	66	123	106	95	86	91.0	7.4
8–9	80	91	56	126	112	98	87	92.9	8.5
9–10	80	93	59	126	111	99	89	93.9	8.1

Treadmill (Pre–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	110	112	96	150	126	141	104	119.9	7.5

Treadmill (Post–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	103	112	75	156	133	123	106	115.4	9.6

Treadmill (Pre–training) – Heart Rate

time (min)	A	B	C	D	E	F	G	MEAN	± SEM
0–1	78	77	81	85	112	85	91	87.0	4.5
1–2	79	82	81	96	111	86	91	89.4	4.2
2–3	81	79	77	99	113	86	93	89.7	4.9
3–4	83	81	78	103	109	87	91	90.3	4.4
4–5	86	83	80	109	109	91	93	93.0	4.5
5–6	87	82	80	110	106	94	93	93.1	4.3
6–7	85	79	78	115	102	93	91	91.9	5.0
7–8	86	80	78	114	100	91	90	91.3	4.7
8–9	89	85	82	113	106	97	94	95.1	4.2
9–10	91	84	83	116	106	98	93	95.9	4.5

Treadmill (Post–training)

time (min)	A	B	C	D	E	F	G	MEAN	± SEM
0–1	70	75	76	95	99	86	90	84.4	4.2
1–2	72	76	76	104	97	87	90	86.0	4.5
2–3	74	78	73	107	98	85	90	86.4	4.8
3–4	75	80	76	108	98	87	90	87.7	4.6
4–5	77	79	76	113	99	89	92	89.3	5.1
5–6	77	80	78	114	99	90	91	89.9	5.0
6–7	77	78	76	114	96	90	91	88.9	5.1
7–8	76	79	76	115	97	88	93	89.1	5.3
8–9	82	83	77	117	100	92	92	91.9	5.1
9–10	83	84	81	120	102	94	96	94.3	5.2

Treadmill (Pre–training) – Rate Pressure Product

SUBJECTS

time (min)	A	B	C	D	E	F	G	MEAN	± SEM
0–1	14.7	12.8	12.0	17.3	24.4	21.1	15.4	16.8	1.7
1–2	15.0	13.9	13.4	21.3	24.5	21.8	15.7	17.9	1.7
2–3	15.2	13.9	12.8	25.5	25.1	21.3	16.5	18.6	2.0
3–4	16.8	14.7	12.1	26.0	24.1	21.1	15.7	18.6	2.0
4–5	17.3	15.4	12.6	27.6	22.9	22.4	16.0	19.2	2.0
5–6	17.3	13.6	12.5	29.2	22.5	22.5	15.5	19.0	2.3
6–7	16.5	13.2	12.2	30.8	21.5	22.2	15.2	18.8	2.5
7–8	16.9	13.8	11.7	30.9	20.4	21.7	15.1	18.6	2.4
8–9	17.9	15.3	12.6	29.4	22.3	23.2	16.6	19.6	2.2
9–10	18.4	14.1	12.7	30.5	22.8	23.8	15.8	19.7	2.4

Treadmill (Post–training)

SUBJECTS

time (min)	A	B	C	D	E	F	G	MEAN	± SEM
0–1	11.7	13.0	10.0	20.5	20.0	19.6	14.5	15.6	1.6
1–2	11.8	12.4	10.3	24.2	19.7	19.6	15.4	16.2	1.9
2–3	12.4	12.7	9.9	26.3	19.4	19.0	15.3	16.4	2.1
3–4	13.0	13.8	10.7	26.9	19.5	19.4	14.9	16.9	2.1
4–5	13.0	13.4	10.5	29.6	20.6	20.6	16.3	17.7	2.5
5–6	13.2	13.0	10.1	31.0	20.7	21.7	15.5	17.9	2.7
6–7	13.2	13.0	10.5	29.5	19.7	21.1	15.2	17.5	2.5
7–8	12.5	13.0	11.6	29.8	19.5	19.5	15.7	17.4	2.4
8–9	14.3	14.4	10.9	33.0	21.7	20.6	15.3	18.6	2.8
9–10	14.8	14.8	11.1	32.6	22.0	21.7	16.9	19.1	2.7

Stairmaster (Pre–training) – Peak Systolic BP

SUBJECTS

FLIGHT #	A	B	C	D	E	F	G	MEAN	± SEM
0–1	183	168	139	180	187	232	165	178.5	12.6
1–2	183	164	138	191	188	222	151	175.7	12.5
2–3	192	172	143	211	187	228	156	182.8	13.3
3–4	197	181	146	227	197	246	160	192.8	15.7
4–5	210	188	157	250	200	246	161	200.3	16.5
5–6	221	206	162	266	201	257	168	210.0	17.8
6–7	222	216	164	290	208	256	181	219.2	19.2
7–8	222	219	165	297	212	258	177	221.3	20.2
8–9	227	227	171	302	210	258	179	224.5	20.2
9–10	234	228	176	205	212	270	179	211.7	14.2

Stairmaster (Post–training)

SUBJECTS

FLIGHT #	A	B	C	D	E	F	G	MEAN	± SEM
0–1	*cath.*	164	114	185	174	232	151	170.0	15.9
1–2	*prob.*	167	114	206	184	227	149	174.5	16.5
2–3		172	120	227	191	217	154	180.2	16.4
3–4		183	129	238	192	226	161	188.2	16.5
4–5		193	142	267	197	234	165	199.7	18.5
5–6		212	145	284	199	247	164	208.5	21.1
6–7		222	152	299	205	253	179	218.3	21.5
7–8		228	158	303	208	251	168	219.3	22.1
8–9		234	157	331	213	253	171	226.5	25.7
9–10		239	165	349	218	254	172	232.8	27.4

* *The pre-training data for subject A were not included in the descriptive statistics or the analysis.*

Stairmaster (Pre–training) – Peak Diastolic BP

FLIGHT #	A	B	C	D	E	F	G	MEAN	± SEM
0–1	87	98	78	96	102	105	88	94.5	4.1
1–2	84	89	66	90	98	92	76	85.2	4.8
2–3	96	90	60	95	94	88	76	83.8	5.5
3–4	81	88	64	103	89	95	78	86.2	5.6
4–5	85	92	66	126	88	92	77	90.2	8.3
5–6	85	96	72	117	91	97	78	91.8	6.5
6–7	87	103	70	123	91	97	81	94.2	7.5
7–8	87	100	66	143	102	95	84	98.3	10.4
8–9	86	105	73	136	93	98	78	97.2	9.2
9–10	88	105	73	136	97	104	84	99.8	8.8

Stairmaster (Post–training)

FLIGHT #	A	B	C	D	E	F	G	MEAN	± SEM
0–1	*cath.*	92	54	94	102	107	83	88.7	7.7
1–2	*prob.*	94	44	97	96	94	76	83.5	8.5
2–3		90	37	97	96	83	74	79.5	9.2
3–4		93	42	108	91	85	77	82.7	9.1
4–5		97	46	114	96	87	73	85.5	9.6
5–6		102	45	122	97	90	76	88.7	10.7
6–7		121	46	129	95	92	78	93.5	12.3
7–8		107	49	132	98	90	77	92.2	11.5
8–9		105	49	139	101	90	77	93.5	12.3
9–10		108	55	145	101	92	78	96.5	12.4

* *The pre-training data for subject A were not included in the descriptive statistics or the analysis.*

Stairmaster (Pre–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	115	119	88	154	123	133	100	119.5	9.6

Stairmaster (Post–training)

	SUBJECTS								
	A	*B*	*C*	*D*	*E*	*F*	*G*	MEAN	± SEM
MAP (mmHg)	*cath. prob.*	123	67	156	128	124	101	116.5	12.2

Stairmaster (Pre–training) – Heart Rate

SUBJECTS

FLIGHT #	A	B	C	D	E	F	G	MEAN	± SEM
0–1	87.0	75.0	78.8	83.7	95.0	85.7	89.6	84.6	2.9
1–2	93.2	82.5	90.4	96.3	103.0	92.0	97.5	93.6	2.9
2–3	90.8	94.0	97.6	103.1	109.0	101.2	106.3	101.9	2.3
3–4	98.7	97.5	97.7	108.4	117.0	104.8	107.7	105.5	3.0
4–5	104.0	102.4	104.8	116.5	118.0	112.0	112.5	111.0	2.5
5–6	108.7	102.4	103.7	121.4	123.0	116.9	111.1	113.1	3.6
6–7	110.1	106.0	107.4	125.0	126.5	116.2	117.7	116.5	3.5
7–8	107.4	105.9	108.1	128.6	127.0	117.1	119.2	117.7	3.8
8–9	111.5	107.0	111.1	135.7	124.7	118.5	119.2	119.4	4.2
9–10	110.1	109.8	109.8	137.6	128.6	121.4	120.0	121.2	4.4

Stairmaster (Post–training)

SUBJECTS

FLIGHT #	A	B	C	D	E	F	G	MEAN	± SEM
0–1	*cath.*	82.2	76.0	92.0	93.0	88.5	91.5	87.2	2.8
1–2	*prob.*	93.7	84.0	103.6	100.0	91.1	101.5	95.7	3.0
2–3		93.2	96.2	108.4	113.0	96.2	104.2	101.9	3.2
3–4		98.7	98.8	115.1	114.5	103.7	102.7	105.6	3.0
4–5		103.8	103.6	115.1	119.2	106.1	110.9	109.8	2.6
5–6		102.5	101.2	125.0	122.4	111.1	112.5	112.5	4.0
6–7		106.3	108.7	126.1	126.9	108.7	115.1	115.3	3.7
7–8		110.1	106.1	129.1	130.3	111.1	113.5	116.7	4.2
8–9		111.5	108.0	136.9	129.1	114.8	120.8	120.2	4.5
9–10		113.4	106.9	141.9	130.3	115.1	116.0	120.6	5.3

* *The pre-training data for subject A were not included in the descriptive statistics or the analysis.*

Stairmaster (Pre–training) – Rate Pressure Product

SUBJECTS

FLIGHT #	A	B	C	D	E	F	G	MEAN	± SEM
0–1	15.9	12.6	11.0	15.1	17.8	19.9	14.8	15.2	1.3
1–2	17.1	13.5	12.5	18.4	19.4	20.4	14.7	16.5	1.4
2–3	17.4	20.3	14.0	22.4	20.4	23.1	16.6	19.5	1.4
3–4	19.4	17.6	14.3	24.6	23.0	25.8	17.2	20.4	1.9
4–5	21.8	19.3	16.5	29.1	23.6	27.6	18.1	22.4	2.1
5–6	24.0	21.1	16.8	32.3	24.7	30.0	18.7	23.9	2.5
6–7	24.4	22.9	17.6	36.3	26.3	29.7	21.3	25.7	2.7
7–8	23.8	23.2	17.8	38.2	26.9	30.2	21.1	26.2	3.0
8–9	25.3	24.3	19.0	41.0	26.2	30.6	21.3	27.1	3.2
9–10	25.8	25.0	19.3	42.0	27.3	32.8	21.5	28.0	3.4

Stairmaster (Post–training)

SUBJECTS

FLIGHT #	A	B	C	D	E	F	G	MEAN	± SEM
0–1	*cath.*	13.5	8.7	17.0	16.2	20.5	13.8	15.0	1.6
1–2	*prob.*	15.6	9.6	21.3	18.4	20.7	15.1	16.8	1.8
2–3		16.0	11.5	24.6	21.6	20.9	16.0	18.4	1.9
3–4		18.1	12.7	27.4	22.0	23.4	16.5	20.0	2.2
4–5		20.0	14.7	30.7	23.5	24.8	18.3	22.0	2.3
5–6		21.7	14.7	35.5	24.4	27.4	18.5	23.7	3.0
6–7		23.6	16.5	37.7	26.0	27.5	20.6	25.3	3.0
7–8		25.1	16.8	39.1	27.1	27.9	19.1	25.9	3.2
8–9		26.1	17.0	43.8	27.5	29.0	20.7	27.4	3.8
9–10		27.1	17.6	47.0	28.4	29.2	20.0	28.2	4.2

* *The pre-training data for subject A were not included in the descriptive statistics or the analysis.*

APPENDIX E:

Analysis of Variance Tables

ANOVA Summary Tables

Maximal Voluntary Contraction (kg)
Isometric Handgrip

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	692.4	6			
Condition	292.6	1	292.6	10.4	0.017
Error	168.4	6	28.1		
Total	1153.4	13			

One Repetition Maximum (kg)
Single-Arm Curl (kg)

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	833.2	6			
Condition	780.0	1	780	10.9	0.016
Error	429.4	6	71.6		
Total	2042.7	13			

ANOVA Summary Tables

One Repetition Maximum (kg)
Single-Leg Press (kg)

Source of Variation	Sum of the Squares	Degrees of Freedom	Mean Square	F ratio	P value
Subjects	1412.4	6			
Condition	1783.1	1	1783.1	28.6	0.002
Error	373.9	6	62.3		
Total	3569.4	13			

One Repetition Maximum (kg)
Double-Leg Press (kg)

Source of Variation	Sum of the Squares	Degrees of Freedom	Mean Square	F ratio	P value
Subjects	8075.0	6			
Condition	7087.5	1	7087.5	36.2	0.001
Error	1175.0	6	195.8		
Total	16337.5	13			

ANOVA Summary Tables

Peak Systolic Pressure (mmHg)
Rest

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	4651.9	6			
Condition	2.6	1	2.6	0.1	
Error	246.4	6	41.1		
Total	4900.9	13			

Peak Diastolic Pressure (mmHg)
Rest

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	707.7	6			
Condition	12.1	1	12.1	0.9	
Error	81.4	6	13.6		
Total	801.2	13			

ANOVA Summary Tables

Mean Arterial Pressure (mmHg)
Rest

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	1957.9	6			
Condition	3.5	1	3.5	0.1	
Error	417.0	6	69.5		
Total	2378.4	13			

Heart Rate (bpm)
Rest

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	1222.4	6			
Condition	25.8	1	25.8	0.9	
Error	180.7	6	30.1		
Total	1428.9	13			

ANOVA Summary Table

Rate Pressure Product
Rest

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	60.0	6			
Condition	0.6	1	0.6	0.8	
Error	5.1	6	0.9		
Total	65.7	13			

ANOVA Summary Table

Peak Systolic Pressure (mmHg)
Single-Arm Curl

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	109294.2	6			
Condition	24874.9	2	12437.5	13.8	0.001
Error	10824.9	12	902.1		
Repetitions	23942.4	9	2660.3	38.3	< 0.001
Error	3752.5	54	69.5		
Cond. x Reps.	5567.2	18	309.3	6.4	< 0.001
Error	5212.3	108	48.3		
Total	183468.5	209			
Residual	19789.8	174			

ANOVA Summary Table

Peak Systolic Pressure (mmHg)
Single-Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	190288.3	6			
Condition	13382.2	2	6691.1	5.8	0.017
Error	13951.1	12	1162.6		
Repetitions	42222.8	11	3838.4	25.6	< 0.001
Error	9889.4	66	149.8		
Cond. x Reps.	3130.7	22	142.3	3.2	< 0.001
Error	5878.6	132	44.5		
Total	278743.2	251			
Residual	29719.1	210			

ANOVA Summary Table

Peak Systolic Pressure (mmHg)
Double–Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	172378.0	6			
Condition	17999.5	2	8999.7	4.9	0.027
Error	22082.6	12	1840.2		
Repetitions	43917.4	11	3992.5	43.7	< 0.001
Error	6028.8	66	91.3		
Cond. x Reps.	5868.8	22	266.8	5.8	< 0.001
Error	6053.1	132	45.9		
Total	274328.2	251			
Residual	34164.5	210			

ANOVA Summary Table

Peak Diastolic Pressure (mmHg)
Single-Arm Curl

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	8136.3	6			
Condition	23999.1	2	11999.6	20.7	< 0.001
Error	6964.9	12	580.4		
Repetitions	9668.5	9	1074.3	20.6	< 0.001
Error	2809.9	54	52.0		
Cond. x Reps.	2611.6	18	145.1	5.1	< 0.001
Error	3056.4	108	28.3		
Total	57246.7	209			
Residual	12831.2	174			

ANOVA Summary Table

Peak Diastolic Pressure (mmHg)
Single–Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	69856.9	6			
Condition	12887.6	2	6443.8	7.6	0.007
Error	10219.1	12	851.6		
Repetitions	18648.7	11	1695.3	18.8	< 0.001
Error	5943.3	66	90.0		
Cond. x Reps.	2538.4	22	115.4	2.4	< 0.001
Error	6219.6	132	47.1		
Total	126313.6	251			
Residual	22381.9	210			

ANOVA Summary Table

Peak Diastolic Pressure (mmHg)
Double-Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	56051.3	6			
Condition	15010.4	2	7505.2	6.1	0.014
Error	14704.3	12	1225.4		
Repetitions	13893.5	11	1263.0	16.0	< 0.001
Error	5226.4	66	7902		
Cond. x Reps.	2175.6	22	98.9	2.1	0.005
Error	6137.7	132	46.5		
Total	113199.2	251			
Residual	26068.4	210			

ANOVA Summary Table

Heart Rate (bpm)
Single–Arm Curl

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	5754.7	6			
Condition	5556.0	2	2778.0	29.6	< 0.001
Error	1124.9	12	93.7		
Repetitions	3651.8	9	405.8	7.5	< 0.001
Error	2905.4	54	53.8		
Cond. x Reps.	1301.6	18	72.3	1.7	0.056
Error	4684.3	108	43.4		
Total	24978.7	209			
Residual	8714.6	174			

ANOVA Summary Table

Heart Rate (bpm)
Single–Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	18370.2	6			
Condition	2206.3	2	1103.1	4.0	0.045
Error	3297.0	12	274.7		
Repetitions	7610.6	11	691.9	12.6	< 0.001
Error	3638.3	66	55.1		
Cond. x Reps.	834.6	22	37.9	1.2	0.282
Error	4270.8	132	32.4		
Total	40227.7	251			
Residual	11206.1	210			

ANOVA Summary Table

Heart Rate (bpm)
Double-Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	16606.2	6			
Condition	3918.9	2	1959.4	7.8	0.006
Error	3013	12	251.1		
Repetitions	10910.7	11	991.9	38.5	< 0.001
Error	1700.7	66	25.8		
Cond. x Reps.	759.2	22	34.5	1.2	0.239
Error	3725.5	132	28.2		
Total	40634.1	251			
Residual	8439.2	210			

ANOVA Summary Table

Rate Pressure Product (x 1000)
Single-Arm Curl

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	1009.1	6			
Condition	748.0	2	374.0	37.1	< 0.001
Error	120.9	12	10.1		
Repetitions	575.5	9	63.9	24.1	< 0.001
Error	143.1	54	2.6		
Cond. x Reps.	156.1	18	8.7	3.9	< 0.001
Error	239.7	108	2.2		
Total	2992.3	209			
Residual	503.6	174			

ANOVA Summary Table

Rate Pressure Product (x 1000)
Single-Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	3487.1	6			
Condition	405.6	2	202.8	6.6	0.011
Error	370.9	12	30.9		
Repetitions	1260.4	11	114.6	20.7	< 0.001
Error	365.7	66	5.5		
Cond. x Reps.	105.0	22	4.8	2.5	< 0.001
Error	249.7	132	1.9		
Total	6244.5	251			
Residual	986.3	210			

ANOVA Summary Table

Rate Pressure Product (x 1000)
Double-Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	2864.8	6			
Condition	660.7	2	330.3	8.8	0.004
Error	449.4	12	37.5		
Repetitions	1637.2	11	148.8	61.9	< 0.001
Error	158.6	66	2.4		
Cond. x Reps.	177.7	22	8.1	4.4	< 0.001
Error	242.8	132	1.8		
Total	6191.2	251			
Residual	850.8	210			

ANOVA Summary Tables

Mean Arterial Pressure (mmHg)
Single-Arm Curl

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	4384.5	6			
Condition	644.7	2	322.3	3.1	0.079
Error	1234.7	12	102.9		
Total	6263.8	20			

Mean Arterial Pressure (mmHg)
Single-Leg Press

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	5823.6	6			
Condition	521.2	2	260.6	1.4	0.275
Error	2176.1	12	181.3		
Total	8521.0	20			

ANOVA Summary Table

Mean Arterial Pressure (mmHg)
Double-Leg Press

Source of Variation	Sum of the Squares	Degrees of Freedom	Mean Square	F ratio	P value
Subjects	7128.0	6			
Condition	589.7	2	294.9	3.4	0.064
Error	1026.3	12	85.5		
Total	8744.0	20			

ANOVA Summary Tables

Average Heart Rate (bpm)
Single-Arm Curl (kg)

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	606.6	6			
Condition	346.4	2	173.2	11.2	0.002
Error	186.3	12	15.5		
Total	1139.2	20			

Average Heart Rate (bpm)
Single-Leg Press (kg)

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	1323.3	6			
Condition	263.5	2	131.8	5.9	0.016
Error	267.8	12	22.3		
Total	1854.7	20			

ANOVA Summary Table

Average Heart Rate (bpm)
Double–Leg Press (kg)

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	1404.6	6			
Condition	274.7	2	137.3	6.8	0.010
Error	244.0	12	20.3		
Total	1923.2	20			

ANOVA Summary Tables

Peak Systolic Pressure (mmHg)
Isometric Handgrip @ 50% MVC

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	13546.5	6			
Condition	275.4	2	137.7	0.9	
Error	1757.2	12	146.4		
Total	15579.1	20			

Peak Diastolic Pressure (mmHg)
Isometric Handgrip @ 50% MVC

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	1929.9	6			
Condition	271.1	2	135.6	2.1	0.167
Error	783.5	12	65.3		
Total	2984.6	20			

ANOVA Summary Tables

Mean Arterial Pressure (mmHg)
Isometric Handgrip @ 50% MVC

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	7594.6	6			
Condition	173.4	2	86.7	0.8	
Error	1266.6	12	105.5		
Total	9034.6	20			

Heart Rate (bpm)
Isometric Handgrip @ 50% MVC

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	1553.6	6			
Condition	32.7	2	16.3	0.5	
Error	386.7	12	32.2		
Total	1973.0	20			

ANOVA Summary Table

Rate Pressure Product
Isometric Handgrip @ 50% MVC

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	144.0	6			
Condition	2.6	2	1.3	0.5	
Error	34.5	12	2.9		
Total	181.1	20			

ANOVA Summary Table

Peak Systolic Pressure (mmHg)
Treadmill

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	178562.3	6			
Condition	3661.8	1	3661.8		
Error	3131.7	6	521.9	7	0.037
Time (min.)	1896.6	9	210.7		
Error	6954.3	54		1.6	0.128
			128.8		
Cond. x Time	634.5	9			
Error	1798.0	54	70.5	2.1	0.043
			33.3		
Total	196639.2	139			
Residual	11884.0	114			

ANOVA Summary Table

Peak Diastolic Pressure (mmHg)
Treadmill

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	34364.6	6			
Condition	596.6	1	596.6	2.1	0.192
Error	1671.9	6	278.6		
Time (min.)	516.9	9	57.4	1.3	0.267
Error	2416.8	54	44.8		
Cond. x Time	98.1	9	10.9	0.5	
Error	1159.0	54	21.5		
Total	40823.8	139			
Residual	5247.6	114			

ANOVA Summary Table

Mean Arterial Pressure (mmHg)
Treadmill

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	5891.7	6			
Condition	68.6	1	68.6	1.1	0.341
Error	382.9	6	63.8		
Total	6343.2	13			

ANOVA Summary Table

Heart Rate (bpm)
Treadmill

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	16715.7	6			
Condition	291.5	1	291.5	2.7	0.149
Error	646.9	6	107.8		
Time (min.)	972.8	9	108.1	4.7	< 0.001
Error	1236.2	54	22.9		
Cond. x Time	13.8	9	1.5	0.4	
Error	185.8	54	3.4		
Total	20062.7	139			
Residual	2068.9	114			

ANOVA Summary Table

Rate Pressure Product (x 1000)
Treadmill

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	3842.8	6			
Condition	65.7	1	65.7	4.6	0.075
Error	86.6	6	14.4		
Time (min.)	112.2	9	12.5	2.6	0.013
Error	255.6	54	4.7		
Cond. x Time	6.2	9	0.7	1.1	0.392
Error	34.6	54	0.6		
Total	4403.8	139			
Residual	376.8	114			

ANOVA Summary Table

Peak Systolic Pressure (mmHg)
Stairmaster

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	176761.0	5			
Condition	0.4	1	0.4	0.0	0.000
Error	5533.6	5	1106.7		
Flight	44183.4	9	4909.3	11.8	< 0.001
Error	18647.0	45	414.4		
Cdn.xFlight	1685.3	9	187.3	1.2	0.305
Error	6894.1	45	153.2		
Total	253705.0	119			
Residual	31074.8	95			

ANOVA Summary Table

Peak Diastolic Pressure (mmHg)
Stairmaster

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	40642.9	5			
Condition	410.7	1	410.7	0.9	
Error	2358.7	5	471.7		
Flight	3320.1	9	368.9	3.1	0.006
Error	5394.5	45	119.9		
Cdn.xFlight	77.3	9	8.6	0.7	
Error	567.3	45	12.6		
Total	52771.5	119			
Residual	8320.5	95			

ANOVA Summary Table

Mean Arterial Pressure (mmHg)
Stairmaster

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	6982.0	5			
Condition	27.0	1	27.0	0.5	
Error	257.0	5	51.4		
Total	7266.0	11			

ANOVA Summary Table

Heart Rate (bpm)
Stairmaster

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	6275.1	5			
Condition	0.2	1	0.2	0.0	
Error	229.1	5	45.8		
Flight	14249.9	9	1583.3	79.7	< 0.001
Error	893.6	45	19.9		
Cdn.xFlight	47.7	9	5.3	1.1	0.364
Error	211.8	45	4.7		
Total	21907.5	119			
Residual	1334.5	95			

ANOVA Summary Table

Rate Pressure Product (x 1000)
Stairmaster

Source of Variation	*Sum of the Squares*	*Degrees of Freedom*	*Mean Square*	*F ratio*	*P value*
Subjects	3390.4	5			
Condition	1.5	1	1.5	0.1	
Error	69.5	5	13.9		
Flight	2209.3	9	245.5	17.1	< 0.001
Error	644.2	45	14.3		
Cdn.xFlight	4.5	9	0.5	0.7	
Error	33.9	45	0.8		
Total	6353.2	119			
Residual		95			