WEIGHTLIFTING TRAINING IN
CARDIAC EXERCISE REHABILITATION

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By

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ABSTRACT

The purpose of this thesis investigation was to evaluate the effectiveness of dynamic strength training as an additional mode of exercise rehabilitation, in patients with coronary artery disease and well documented evidence of a previous myocardial infarction. The effects of 10 weeks (20 sessions) of combined weightlifting and aerobic training (WtAer)(n=10) were compared with aerobic training (Aer)(n=8) alone, on indices of strength and aerobic exercise capacity in 18 male patients with coronary artery disease (CAD). Initial test(s) performance was similar between groups.

Post Aer, the maximum weightlifting strength (1RM) in single-arm curl, single-leg press, and single-knee extension exercises increased by 13% ($\bar{x}$ = 11.8 to 13.3 kg; $P < 0.01$), 4% ($\bar{x}$ = 97 to 101 kg; N.S.), and 5% ($\bar{x}$ = 28.2 to 29.7 kg; N.S.) respectively; corresponding gains with AerWt were 43% ($\bar{x}$ = 12.2 to 17.4 kg; $P < 0.01$), 21% ($\bar{x}$ = 99 to 120 kg; $P < 0.01$), and 24% ($\bar{x}$ = 29 to 36 kg; $P < 0.01$). Following Aer the initial 1RM could be lifted an average of 4 times, compared to 14 times after AerWt. Neither Aer nor AerWt showed significant improvements in peak torque in either isokinetic single-knee extension at 90°/s and 180°/s or single-leg press exercise at 30°/s and 75°/s. Maximum progressive incremental cycle ergometer performance (Wmax) increased by 2% with Aer ($\bar{x}$ = 1088 to 1113 kpm/min; N.S.) and by 15% ($\bar{x}$ = 1030 to 1180 kpm/min; $P < 0.05$) with AerWt. Cycling time at 80% of initial Wmax before attaining a Borg RPE of 7 for the legs, increased by 11% ($\bar{x}$ = 604 to 672s; N.S.) and by 109% ($\bar{x}$ = 541 to 1128s; $P < 0.05$) with Aer and AerWt respectively.

In these patients with CAD, AerWt was a more effective method of increasing aerobic performance and strength than Aer alone. In order for cardiac exercise rehabilitation therapy to optimize the strength and functional capacities of CAD patients it may be useful to incorporate appropriately monitored weightlifting training into the traditional aerobic exercise regimen.

That which is done out of love always takes place beyond good and evil.

F. Nietzsche

This work is dedicated to my wife, Lynn, and to my family for their loving support.

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For this relief, much thanks.

W. Shakespeare

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CHAPTER 1: BACKGROUND AND STATEMENT OF PURPOSE

1.1 Introduction

Cardiovascular disease (CVD) is the leading cause of disability and death in Canada (Ableson, Paddon and Strohmenger, 1983); it is estimated that approximately 2.6 million men, women, and children have CVD, and it causes greater mortality than all other diseases combined, nearly 80,000 people annually. The financial cost to the Canadian economy was estimated in 1982 to be 3.3 billion dollars per year in lost wages and medical costs (Ableson, Paddon and Strohmenger, 1983).

Coronary artery disease (CAD) is the most common type of CVD and is almost always caused by atherosclerosis. After many years of insidious progression, atherosclerosis may result in angina pectoris (AP), myocardial infarction (MI), congestive heart failure, stroke, or sudden death. Myocardial infarction alone is responsible for 60% of all CVD related deaths (Ableson, Paddon and Strohmenger, 1983).

1.2 Underlying Pathology of CAD

1.2.1 Atherosclerotic Process

The exact sequence of events that ulimately leads to severe obstruction of coronary arteries by atheromatous plaques is unknown; most investigators believe the process to be lifelong, beginning in childhood or early adulthood. In the young, the initial manifestation of atherosclerosis is the fatty streaking of the major vessels (Ross and Glomset, 1976). Lipid materials, principally cholesterol, move from the blood stream and collect in smooth muscle cells in the intima of the artery. These streaks usually occur in the proximal portion of major coronary arteries, particularly at vessel bifurcation or sites of curvature (Ross and Glomset, 1976). Fatty streaking causes little obstruction of the vessel lumen and no clinical symptoms.

Over many decades this lipid deposit may cause an irritation within the vessel wall which gives rise to scarlike, fibrous tissue that builds up around the deposit forming a plaque. This fibrous plaque lesion protrudes into, and partially occludes, the lumen. If the fibrous plaque becomes a complicated lesion due to hemorrhage, calcification, necrosis, and mural thrombosis, then complete blockage of the arterial lumen often occurs (Roberts, 1977). This partial narrowing, or total lumenal occlusion, eventually causes ischemic heart disease with all its various symptoms and manifestations (Roberts, 1977).

1.2.2 Major Theories of the Atherosclerotic Process

The response-to-injury hypothesis proposes that any number of factors, including hypertension, viruses and hyperlipidemia injure the arterial endothelium and trigger the atherosclerotic process. If the injury is continuous or repeated, the lesion can enlarge, undergo necrosis or hemorrhage, and result in lumenal occlusion (Ross and Glomset, 1976).

The monoclonal hypothesis suggests that each atherosclerotic lesion may be a form of benign neoplasm in which the initiation of lesion formation occurs when a single smooth muscle cell develops into a wildly growing cell, triggered by either a mechanical, chemical, or infectious agent (Cohen and Vokonas, 1985).

Finally, the clonal-senescence hypothesis proposes that with aging, a decline in the activity of the crucial stem cells in the intima and media that control smooth muscle proliferation may lead to smooth muscle accumulation in atherosclerotic plaques (Cohen and Vokonas, 1985).

The predisposition of an individual to this disease process is strongly associated with a number of factors that have been identified, and firmly established as risks for CAD.

1.3 Etiology of CAD

1.3.1 Major Modifiable Risk Factors

Epidemiological studies have consistently demonstrated a strong association between certain cultural patterns, lifestyle habits, personal characteristics, and the incidence of CAD. Of these risk factors hypertension, high serum cholesterol levels, and cigarette smoking, are widely recognized as being the most important.

Hypertension appears to be a common and powerful contributor to the evolution of CAD, either independently or in combination with other risk factors (Kannel, Dawber and McGee, 1980; Kannel, Sorlie and Gordon, 1980). Systolic (SBP) arterial pressures and diastolic (DBP) arterial pressures of greater than 140 and 90 mmHg, respectively, have been associated with an increased risk of MI, stroke, and other circulatory complications (Kannel, Dawber and McGee, 1980). For either gender, at any age, the risk of morbidity and mortality from CAD increases with increasing SBP and DBP with no apparent critical value (Kannel, Dawber and McGee, 1980). Indeed, there is a higher incidence of coronary events in individuals whose arterial pressure is in the high "normal" range compared to the low "normal" range (Kannel, Dawber and McGee, 1980).

High total serum cholesterol (TSC) levels have been firmly established as precursors of CAD (Gordon et al., 1981; Hjermann et al., 1979). The harmful component of TSC is the low-density lipoprotein fraction (LDL) which appears to be directly related to the evolution of CAD. The high-density lipoprotein fraction (HDL), however, appears to be inversely related to CAD risk and is thought to be protective in nature (Kannel, Castelli and Gordon, 1979). A relatively low risk of MI is associated with TSC levels below 200 mg/dl, while above 260 mg/dl the risk of MI is extremely high (Kannel, Castelli and Gordon, 1979). Within the range of values usually encountered in countries with a high CAD incidence (185 to 335 mg/dl) the TSC related risk of CAD may increase over 5 fold, depending on the presence or absence of other risk factors (Kannel, Castelli and Gordon, 1979).

Cigarette smoking is estimated to be responsible for 25% of all CAD related deaths and is the most significant, preventable cause of premature death and disability in Canada (Ableson, Paddon and Strohmenger, 1983). The risk of CAD, MI, and sudden death is greater in persons who smoke, and increases according to the number of cigarettes smoked. The strength of cigarette smoking as a predictor of CAD depends on the population observed; this is probably due to the influence of other risk factors. The risk of suffering an MI in smokers may be 10 times greater in men aged 45 to 54 years, and 5 times greater in men aged 35 to 44 years, compared to the general population. The rate of MI is lower among those who have quit smoking than among current smokers (Kannel, McGee and Castelli, 1984).

1.3.2 Other Risk Factors

Risk factors which are unavoidable, those beyond an individual's control, are age, gender, race and ethnic origin, and family history. The incidence of CAD increases with age and is more predominant in males than females, particularly in young ages, but it is doubtful if either factor exerts an independent influence on the incidence of CAD (Kannel and Schatzkin, 1983). The relative contributions of racial differences and genetic factors in determining the risk of CAD have not yet been clearly discerned (Kannel and Schatzkin, 1983).

Obesity (Gordon and Kannel, 1976), diabetes (Garcia et al., 1976) and behavior characterised by excessive competitiveness, chronic impatience, and a strong sense of time urgency (Type A personality) (Rosenman et al., 1976) have all been shown to be associated with an increased risk of CAD . Finally, in adult males an inverse relationship appears to exist between their level of habitual physical activity and the risk of CAD (Kannel and Sorlie, 1979; Morris et al., 1980). The rate of CAD mortality in adult males has been reported to be positively related to a relative sedentary lifestyle in both retrospective occupational (Morris et al., 1953) and prospective leisure (Kannel and Sorlie, 1979; Morris et al., 1980; Paffenbarger, Wing and Hyde, 1978) studies of activity levels.

1.4 Approaches to the exercise rehabilitation of CAD - a historical perspective

1.4.1 Restriction of physical mobilization (1900 to 1930's)

Over two hundred years ago Heberden advocated physical activity as therapy for patients with angina pectoris (Heberden, 1772). However, in 1912 the clinical description of myocardial infarction by Herrick implied that during physical exertion these patients were at an increased risk of experiencing a ventricular aneurysm or rupture, as well as arterial hypoxemia (Herrick, 1912). For these reasons myocardial infarction patients were kept immobile for 6 to 8 weeks. Subsequent pathologic studies (Mallory, White and Salcedo-Salgar, 1939) of experimental MI demonstrated that at least six weeks was required until the majority of the necrotic myocardium was replaced by firm scar tissue. Based on these findings, the practice of restricted physical activity in MI patients was firmly established.

Patients who sustained an MI in the early 1900's were routinely subjected to long periods in hospital and protracted bed rest. The accepted practice immediately following the cardiac event was virtually complete immobilization for six weeks, the anticipated time of healing (Lewis, 1933). Following hospital discharge patients were told to avoid physical activity; exertion comparable to climbing stairs was forbidden for one year after the event. A small percentage returned to work after many months of convalescence at home, but the majority did not resume their pre cardiac event lifestyle.

1.4.2 Early liberalization of activity restriction (1940's to late 1960's)

Physical mobilization began to play a partial role in the management of MI patients in the 1940's when evidence of the adverse effects of enforced bed rest following a cardiac event (Dock, 1944; Harrison, 1944; Taylor, 1949) motivated Levine and co-workers to begin "chair" treatment for pre-discharge acute thrombosis patients (Levine and Lown, 1951). These investigators theorized that the early use of a bedside chair for stabilized patients with acute thrombosis would reduce cardiac work by decreasing venous return, as well as diminish thromboembolic and respiratory complications (Levine and Lown, 1951).

By the 1950's, early ambulation (3 to 5 minutes of walking, twice daily, during the fourth week post MI) began to be encouraged, and was shown to be safe, in appropriately selected patients (Newman et al., 1952). Although physical activity was utilized with increasing frequency in the care of MI patients during the 1950's (Levine and Lown, 1951; Cain, Frasher and Stivelman, 1961; Hellerstein and Ford, 1957), a more aggressive pattern of physical rehabilitation for selected CAD patients was not recommended until the late 1960's, when research studies on exercise in CAD began to proliferate.

1.4.3 Enhancement of Physical Work Capacity

In 1968 a key study by Saltin et al. demonstrated that prolonged immobilization with bed rest resulted in a decrease in an individual's cardiovascular function and physical work capacity (PWC) (Saltin et al., 1968). These authors reported a 20 to 25% decline in the maximal oxygen uptake ($\dot{V}O_2$ max) of healthy males after 2 weeks of bed rest, and a decrease of up to 46%, following 3 weeks (Saltin et al., 1968). The decrement in $\dot{V}O_2$ max was associated with similar declines in maximum cardiac output ($\dot{Q}_c$) and maximum stroke volume ($\dot{V}s$). These findings inferred that the traditional patient management practices of rest and immobilization may further weaken the already impaired oxygen transport system, and the potentially ischemic myocardium, of acute MI patients.

Another major result of the investigation by Saltin and colleagues (1968) was that at least 3 weeks (or longer for those with initially high fitness levels) of exercise were required for restoration to the subject's pre-rest status (Saltin et al., 1968). Also of particular importance to those concerned with cardiac rehabilitation was the conclusion that a long history of restricted physical activity, and extremely low $\dot{V}O_2$ max, did not preclude rapid improvement with physical training (Saltin et al., 1968).

Following these landmark investigations (Saltin et al., 1968) numerous studies were conducted to investigate the safety and efficacy of physical training programmes in CAD patients. The results were that appropriately conducted training programmes may improve the exercise tolerance of most uncomplicated CAD patients (Bjernulf, Boberg and Froberg, 1974; Clausen, Larsen and Trap-Jensen, 1969; Clausen and Trap-Jensen, 1970; Detry and Bruce, 1971; Detry et al., 1971; Kasch and Boyer, 1969; Redwood, Rosing and Epstein, 1972; Rousseau, Brasseur and Detry, 1973; Varnauskas et al., 1966), with little risk (Sanne, 1971).

1.5 Physical Training in CAD

1.5.1 Aerobic endurance training

Submaximal aerobic exercise training has been shown to improve both the functional capacity and the $\dot{V}O_2$ max in CAD patients (Detry and Bruce, 1971; Detry et al., 1971; ; Clausen and Trap-Jensen, 1970; Kasch and Boyer, 1969; Sanne, 1973; Paterson et al., 1979), and even in those with angina pectoris (Clausen and Trap-Jensen, 1976; Redwood, Rosing and Epstein, 1972). The magnitude of the increase in $\dot{V}O_2$ max appears to vary more in CAD patients than in normal individuals of similar age. The $\dot{V}O_2$ max in sedentary, healthy, young (Saltin et al., 1968; Clausen et al., 1973; Ekblom et al., 1968; Rowell, 1974), middle-aged (Hanson et al., 1968; Hartley et al., 1969), and older subjects (Seals et al., 1984) after training may increase from 10 - 30%, but in patients with CAD the reported range varies from an absolute decrease (Clausen and Trap-Jensen, 1976) to increases of 56% (Kasch and Boyer, 1969). In normal and CAD patients the increase in $\dot{V}O_2$ max that is obtained with training is dependent upon age, the initial $\dot{V}O_2$ max, and the intensity and duration of training (Saltin et al., 1968; Ekblom et al., 1969; Hartley et al., 1969). The variation in CAD patients is especially apparent when expressed as a percentage of pre-training values, and when progress is gauged by symptom-limited $\dot{V}O_2$ max, when exercise is terminated because of signs or symptoms other than fatigue (Clausen, 1976). An improvement in symptom limited $\dot{V}O_2$ max of 32 - 56% has been reported in patients with angina pectoris (Detry and Bruce, 1971; Detry et al., 1971; Redwood, Rosing and Epstein, 1971). Most CAD patients begin exercise training with a relatively low initial $\dot{V}O_2$ max and increase to post-training values which rarely exceed 35 ml/kg/min. (Haskell, 1984).

1.5.2 Mechanisms responsible for increases in exercise capacity

The circulatory adapations which may contribute to a higher $\dot{V}O_2$ max include increases in maximal heart rate (HR max), maximal stroke volume ($\dot{V}s$ max), and maximal arteriovenous oxygen content difference ($AVDO_2$ max). In an individual with normal pulmonary function the respiratory system probably imposes no limitation on $\dot{V}O_2$ max (Saltin et al., 1968; Dempsey et al., 1982; Johnson, 1967). Whether training induced increases in the functional capacity are caused primarily by central cardiac changes or by peripheral adaptations in the exercising muscles, has been a matter of contention (Clausen, 1976; Amsterdam et al., 1981; Blomqvist and Saltin, 1983).

1.5.3 Peripheral circulatory capacity

Exercise training results in a greater oxygen extraction at maximal exercise, and at each submaximal work load in the trained limb (Clausen et al., 1973; Saltin et al., 1968) and may increase the total systemic $AVDO_2$ (Detry et al., 1971). In healthy, young, previously sedentary subjects, approximately 50% of the increase in $\dot{V}O_2$ max after training has been attributed to an increased $AVDO_2$ (Saltin et al., 1968; Clausen, 1976; Ekblom et al., 1968). In one group of healthy middle-aged subjects (Hanson et al., 1968), and some CAD patients (Detry et al., 1971), however, the entire increase in $\dot{V}O_2$ max has been attributed to an increase in $AVDO_2$.

Numerous investigators in the 1960's, 1970's, and early 1980's suggested that this increase in $AVDO_2$ following training, supported the concept that peripheral circulatory adaptations, rather than central cardiac function changes, were most important for the increased work capacity observed in trained CAD patients (Clausen, 1976; Varnauskas et al., 1966). This conclusion was supported by a lower stroke volume (Varnauskas et al., 1966; Bergman and Varnauskas,

1970) and a reduced stroke work (Clausen, Larsen and Trap-Jensen, 1969; Clausen and Trap-Jensen, 1970; Detry et al., 1971) at the same exercise intensity after training. Hence the improved exercise capacity and $\dot{V}O_2$ of cardiac patients following training could be attributed to peripheral changes that resulted in a slower heart rate, lower blood pressure, decreased vascular resistance, and an increased $AVDO_2$ in the exercising muscles (Clausen, Larsen and Trap-Jensen, 1969; Clausen and Trap-Jensen, 1970; Varnauskas et al., 1966; Bergman and Varnauskas, 1970; Detry et al., 1971). This suggestion is supported by the fact that the most prominent training effects are evident when testing is performed with the trained limbs (Clausen, Trap-Jensen and Lassen, 1970; Clausen et al., 1973). In normal subjects Clausen and co-workers (1970) observed that the reduction in exercise HR after training of the arms did not carry over to exercise performed with the legs; nor did leg training cause significant reduction of the HR during dynamic arm work (Clausen, Trap-Jensen and Lassen, 1970). Clausen (1976) concluded that the attenuated HR response, the decrease in peripheral vasoconstriction, and the increase in $AVDO_2$ are confined to exercise with trained limbs, and that this is probably mediated by local oxidative metabolic adaptations within the skeletal muscle cells.

1.5.4 Central circulatory capacity

Most training studies in patients with CAD have utilized mild to moderate intensity aerobic-endurance exercise (50 to 70% of $\dot{V}O_2$ max) for a period ranging from 2 - 4 months. Several of these investigators observed an improvement in ejection fraction, determined by radionuclide angiography, at a given submaximal work load (Jenson et al., 1980), but not at maximal exercise (Jenson et al., 1980; Cobb et al., 1982) after exercise training of moderate intensity.

Speculating that the absence of improvement during maximal exercise in these studies may have been due to exercise training of insufficient intensity and duration, Ehsani et al. (1981 and 1982) and Hagberg and colleagues (1983) studied the effects of prolonged (12 months), and intense training (70 - 90% $\dot{V}O_2$ max) on central circulatory function in patients with CAD. Post-training, Ehsani and colleagues (1981) reported a significant increase in $\dot{V}O_2$ max of 34% (expressed as ml/kg/min), and diminished ECG evidence of myocardial ischemia. The ECG findings included a decline in the maximum degree of ST-segment depression during exercise, an increase in the product of HR and SBP (rate-pressure product, RPP) at which ST-segment depression first appeared, and a reduction in ST-segment depression at the same RPP after training (Ehsani et al., 1981). This decrease in ECG evidence of myocardial ischemia was attributed to an exercise-induced improvement in myocardial oxygenation, secondary to enhanced myocardial blood supply; of importance was that these changes had occurred at the same, or higher levels of systemic vascular resistance (Ehsani et al., 1981). Moreover, in another paper, Hagberg, Ehsani and Holloszy (1983) reported an increase in left ventricular stroke volume (18%) at both the same submaximal absolute and relative exercise intensities, and an increase in stroke work (18%), since the ventricular afterload (defined as mean arterial pressure) was unchanged at equivalent exercise intensities after training (Hagberg, Ehsani and Holloszy, 1983). These investigators (Ehsani et al., 1981; Hagberg, Ehsani and Holloszy, 1983) concluded that a programme of intense and prolonged exercise training in selected CAD patients may result in intrinsic myocardial improvements which are not secondary to peripheral muscle adaptations, as suggested by previous findings (Clausen, Larsen and Trap-Jensen, 1969; Clausen and Trap-Jensen, 1970; Detry et al., 1971; Varnauskas et al., 1966).

1.5.5 Peripheral muscle capacity

Weightlifting exercise is a natural part of many daily activities yet the low to moderate intensity aerobic work performed in most cardiac exercise rehabilitation programmes provides a minimal stimulus to improve peripheral muscle strength and power. Thus it seems possible that strength training in conjunction with aerobic exercise may improve the functional capacity of many cardiac patients to a level greater than that which may result from aerobic training alone.

The only published investigation which addressed this hypothesis by Keleman et al. (1986), was a prospective, randomized evaluation of the safety and efficacy of 10 weeks of circuit weight training in CAD patients aged 35 to 75 years. Control patients participated in traditional aerobic-endurance exercise and volleyball, while the experimental group substituted weightlifting for volleyball. The experimental group completed two circuits of 12 to 15 repetitions per exercise at 40% of the subject's single maximum lift (1RM). After training the time to exhaustion in a symptom limited standard Bruce treadmill test, and the overall strength (1RM) of the experimental group increased significantly by 12% (619 to 694 seconds) and 24%, respectively. The control group showed no change in either measure.

These significant gains in strength and treadmill endurance time resulted from a training protocol which involved only 2 leg exercises at a relatively low percentage of maximum strength. In a strength training programme of higher intensity, with more emphasis on leg activities, greater improvements in lower limb strength might be expected. This strategy may also increase the exercise tolerance of selected patients in power oriented lower limb activities such as cycling on an ergometer.

The safety of weighlifting at higher intensities has recently been documented by Haslam et al. (1988) (see Appendix A) who found that up to 10 repetitions of single-arm curl, single- knee extension, and single- leg press exercise at <80% 1RM resulted in clinically acceptable electrocardiogram and intra-arterial blood pressure responses, in 8 patients with CAD and documented evidence of a previous myocardial infarction.

The reduced cardiac function of CAD patients with a previous myocardial infarction often restricts the exercise capacity of these individuals (Hung et al., 1984). However, during exercise on a cycle ergometer, subjective symptoms of pronounced local fatigue in the legs (thigh region) often causes the cessation of exercise, without any evidence of a cardiorespiratory limitation. It seems possible that the reduction in everyday activity that frequently accompanies a myocardial infarction may result in a substantial loss in muscle size and muscle strength, in addition to a decreased aerobic capacity, and thus may contribute to such a symptomatic response. The previously discussed (see 1.3.3) deleterious effects of bed rest on muscle enzyme capacity and fuel utilization (Saltin et al., 1968), and the reduction in functional motor units in older healthy adults as a result of disuse (Larsson, Sjodin and Karlsson, 1978) may also adversely influence the peripheral muscle function of relatively inactive CAD patients (Oldridge et al., 1988).

A recent study by McCartney and colleagues (1988) revealed that patients with the same exercise performance in a progressive incremental cycle ergometer test may exhibit large differences in the maximal power output capacity of their leg muscles. It was concluded that the progressive exercise performance in a patient with powerful legs was most likely restricted by poor cardiovascular function, whereas in the subjects with weak leg muscles this deficit may have been the primary limiting factor to exercise. These investigators suggested that in addition to conventional aerobic endurance exercise, CAD patients with weak leg muscles may also benefit from exercise which specifically addresses the deficit of peripheral muscle strength. It seems likely that carefully monitored weight training, in conjunction with aerobic conditioning, may yield even greater gains in functional capacity than those associated with aerobic training alone, as recently suggested by the work of Kelemen and colleagues (1986).

1.6 Purpose

The purpose of this thesis was to evaluate the effectiveness of dynamic strength training as an additional mode of exercise rehabilitation, in patients with coronary artery disease and well documented evidence of a previous myocardial infarction.

The substantive hypothesis states that those patients who receive supplemental weightlifting training will show greater improvements in objective tests of muscle strength and endurance exercise capacity than subjects in the control group, who perform aerobic training alone.

CHAPTER 2: METHODS

2.1 Subjects

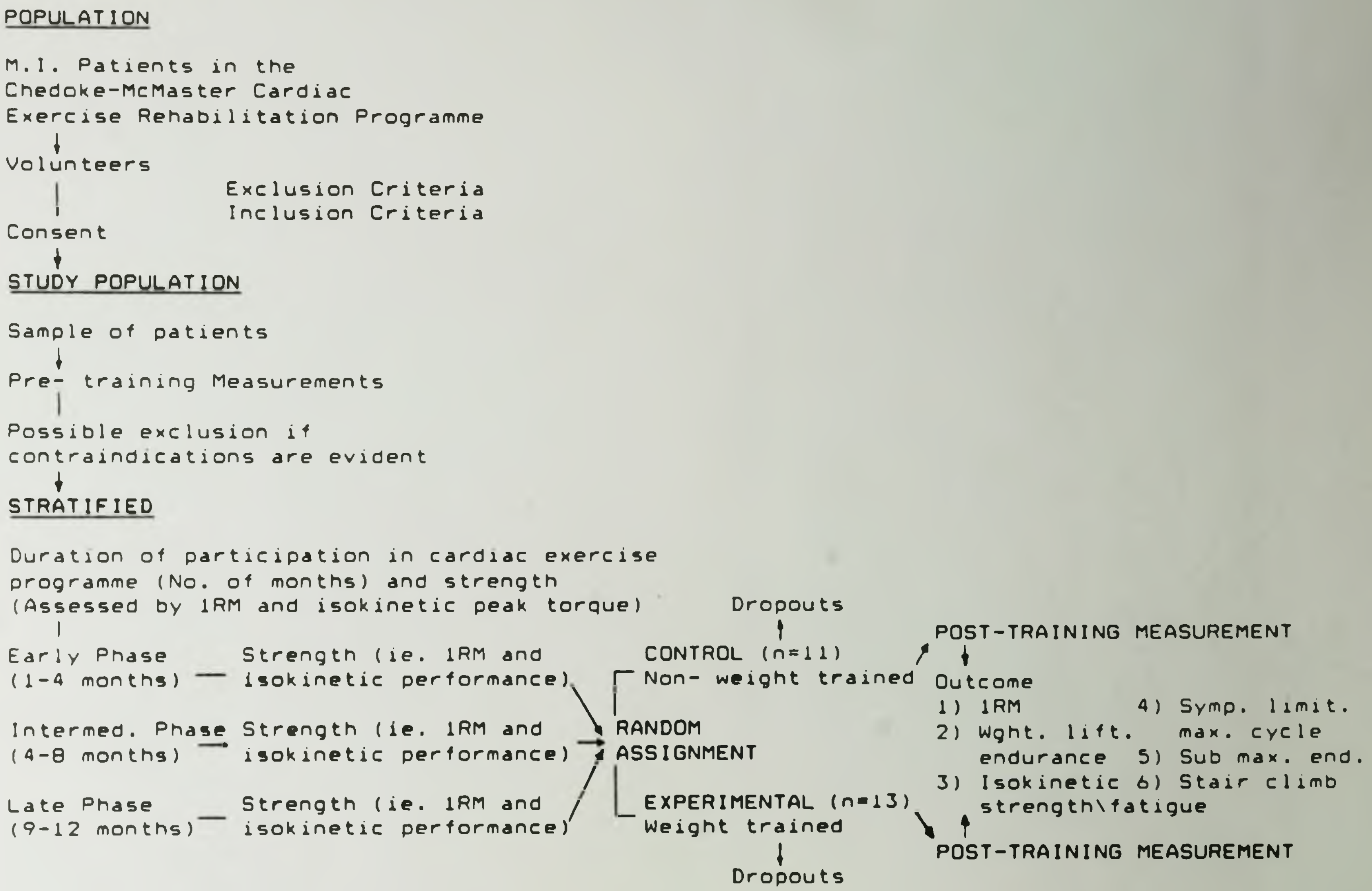
Subjects considered eligible for entry into the study were males, aged 65 years and under, with well documented CAD and evidence of a previous myocardial infarction, who had been participating in the Chedoke-McMaster Cardiac Exercise Rehabilitation Programme for at least one month. Exclusion criteria included unstable angina; resting blood pressure over 160 mmHg or resting diastolic blood pressure over 95 mmHg; abnormal blood pressure response to exercise; acute systemic illness or fever; uncontrolled atrial or ventricular arrhythmias at rest or during exercise; ventricular aneurysm; resting tachycardia (heart rate greater than 120 b/min.); uncontrolled heart failure; evidence of severly depressed pump function; resting ST-segment displacement greater than 2 mm; a maximal heart rate of less than 100 bpm; respiratory limitation; and orthopedic problems that would prohibit exercise (American College of Sports Medicine, 1986, Jones and Campbell, 1982). An understanding of the test procedures, and willingness to participate in the study, was confirmed by the signing of an informed consent document (see Appendix B); the study was approved by the University Ethics Committee. Twenty - four men, with a mean age of 51.8 ± 1.6 years (range 39 to 65), agreed to participate in the study.

2.2 Experimental Design

Following the pre-training testing, subjects were stratified initially according to the length of their participation in the cardiac exercise programme to either an early phase (1-4 months), an intermediate phase (5-8 months), or to a late phase category (9-12 months) (see Figure 1). Participants were also stratified according to their strength capacity in relation to body weight. Measures included: the total weight lifted in single-knee extension, and single-leg press one repetition maximum (1RM); total peak torque in maximum voluntary isokinetic single-leg extension at 90 and 180 deg/s; and single-leg press at 30 and 75 deg/s. The subjects in each category were then randomly assigned to either a weightlifting and aerobic training (AerWt), or aerobic training group (Aer).

2.3 Intervention

Exercise training sessions were held in the Exercise


POPULATION
M.I. Patients in the Chedoke-McMaster Cardiac Exercise Rehabilitation Programme
Volunteers
Exclusion Criteria
Inclusion Criteria
Consent
STUDY POPULATION
Sample of patients
Pre- training Measurements
Possible exclusion if contraindications are evident
STRATIFIED
Duration of participation in cardiac exercise programme (No. of months) and strength (Assessed by 1RM and isokinetic peak torque)
Early Phase (1-4 months)
Strength (ie. 1RM and isokinetic performance)
Intermed. Phase (4-8 months)
Strength (ie. 1RM and isokinetic performance)
Late Phase (9-12 months)
Strength (ie. 1RM and isokinetic performance)
RANDOM ASSIGNMENT
Dropouts
CONTROL (n=11) Non- weight trained
EXPERIMENTAL (n=13) Weight trained
Dropouts
POST-TRAINING MEASUREMENT
Outcome
1) 1RM
2) Wght. lift. endurance
3) Isokinetic strength\fatigue
4) Symp. limit. max. cycle
5) Sub max. end.
6) Stair climb
POST-TRAINING MEASUREMENT

Rehabilitation Laboratory at McMaster University. The training protocol required both the Aer and AerWt groups to attend two sessions of training each week for a total of ten weeks (20 sessions). Global Gym (4141, SR14, multistation, Downsview, Ontario) knee extension and leg press, and Rubicon Industries (Stoney Creek, Ontario) arm curl, variable resistance apparatus were used for the weight training. The weightlifting regimen comprised the following exercises: single-arm curl (SAC), single-leg knee extension (SLE), single-leg calf extension (SCE), and single-leg press (SLP). All exercises were performed by both limbs. During the early training sessions AerWt subjects performed the lifting exercises with the weights set at 40 to 50% of the one repetition maximum (1RM), and were instructed to complete 10 repetitions in SAC and 15 repetitions in the SLE, SCE, and SLP exercises. The 1RM in SAC, SLE, and SLP exercises was re-evaluated every fourth session. Based on the new 1RM, both the relative intensity (% 1RM) and the absolute weight lifted were adjusted concurrently in order to keep the training stimulus constant (see Appendix C). In the final sessions, several AerWt subjects were capable of weight training at 80% 1RM. Initially, two sets of an exercise were completed in each exercise session but the number of sets was progressively increased to three after three weeks (6 sessions) of exercise training. Subjects were encouraged to breathe freely without breath-holding, and in a comfortable fashion while weightlifting. Emphasis was placed on correct body position and technique, and a rhythmic performance of all the weightlifting movements was encouraged.

Prior to weightlifting the AerWt group did a 10 minute warm-up consisting mainly of stretching and calisthenics, after the lifting they performed 30 to 35 minutes of aerobic-endurance activity (see Figure 2). The endurance component of each session comprised: a) arm ergometer exercise, for 4 to 6 minutes at an intensity equivalent to 70% of the maximum achieved heart rate in clinical exercise testing; b) leg cycle ergometry at 60 - 85% of maximal heart rate for 15 to 20 minutes; c) walk\jogging for 10 minutes, at 65 - 70% of functional capacity (max METs). Each exercise session concluded with a warm-down of approximately 5 to 10 minutes, and consisted of exercises of diminishing intensities, e.g. slower walking, stretching, and relaxation activities. The Aer group performed a warm-up, cardiovascular endurance activities, and a warm-down that was similar in nature to those undertaken by the AerWt group. Instead of weightlifting exercises the Aer group

SESSION FORMAT

AerWt Group	Aer Group
A) **WARM-UP** Stretching\calisthenics	Similar to AerWt group minus weight training which was replaced by 25 to 35 mins. of recreational activities at approx. 30 to 40% of max. METS

B) **WEIGHT TRAINING**

SINGLE-ARM CURL	SINGLE-KNEE EXTENSION	SINGLE-LEG PRESS
(10 reps)	(15 reps)	(15 reps)

2 SETS AT 40 TO 50% 1RM INITIALLY

PROGRESSED TO 3 SETS AT 60 TO 80% 1RM

1RM RE-EVALUATED AT 4 SESSION INTERVALS

C) **AEROBIC**

ARM ERGOMETRY - 4 TO 6 MINS. AT APPROX. 70% MAX. H.R.

LEG CYCLE ERGOMETRY - 15 TO 20 MINS. AT APPROX. 60 TO 85% MAX. H.R.

WALK\JOGGING - 10 MINS. AT APPROX. 65 TO 70% MAX METS

D) **WARM DOWN**

REDUCED ACTIVITY - RELAXATION

engaged in recreational activities. Each recreational activity component comprised games or light dancing, at an intensity equivalent to approximately 30 to 40% of the maximum functional capacity (max METs), for 25 to 35 minutes.

2.4 Patient monitoring

The subjects kept individual records of their self-monitored exercise pulse rate, work performed, and any other comments which they felt were pertinent and related to their exercise training. These journals were reviewed thoroughly following each session by the physical instructor. Comments which may have suggested that the patient was having a medical problem were immediately reviewed by the programme physician. In each exercise session the overall programme was closely supervised by a physician and several physical educators. The monitoring of these supervised training sessions, and examination of the exercise log books, ensured that subjects adhered closely to their exercise prescriptions.

2.5 Measurements

Prior to, and following the training period, the subjects participated in several tests to investigate peripheral muscle strength and power, exercise capacity and the ability to perform selected activities of daily living. For a detailed examination of the testing schedule refer to Appendix D.

2.5.1 Maximal weightlifting strength

The one-repetition maximum (1RM) strength was measured on the training apparatus, during several trials on two separate days. Strength was recorded as the greatest number of kilograms lifted in an exercise, throughout a complete range of motion (1RM). The unilateral manoeuvers tested in each limb included: elbow flexion; knee extension; and leg press.

2.5.2 Absolute weightlifting endurance

After training, the subjects attempted to successively lift their pre-training 1RM as many times as possible.

2.5.3 Maximum isokinetic concentric contraction strength

Strength was also assessed isokinetically using both a

Cybex II isokinetic dynamometer, and a Cybex (Lumex, Ronkonkoma, NY) leg press apparatus coupled to the Cybex II dynamometer (Vandervoort, Sale and Moroz, 1984). Torque signals were recorded on a 2 channel oscillograph recorder (Hewlett Packard 7402A, San Diego, CA). Strength was recorded as the maximum peak torque during unilateral knee extension and leg press manoeuvers. In knee extension exercise each leg was extended from an initial 90 degree knee joint angle to full extension (0 degrees), at angular velocities of 90 and 180 deg/s, selected in random order (Thorstensson and Karlsson, 1976). In the leg press exercise, subjects started from a position with each knee at 90 degrees and then exerted maximal force on the lever arm until complete extension of the knee. Testing was performed at lever arm angular velocities of 30 and 75 deg/s, selected in random order (Vandervoort, Sale and Moroz, 1984). Knee extension and leg press maximal strength was defined as the highest torque produced during 3 maximal efforts at each of the angular velocities. Average torque, and the impulse in each contraction were calculated from the recorded torque signals.

2.5.4 Isokinetic Single-Knee Extension Fatiguability

Using a Cybex II isokinetic dynamometer, all subjects performed 25 consecutive maximal knee extensions at 180° deg/s, resuming the starting position passively between each contraction (Thorstensson and Karlsson, 1976). The velocity of 180 deg/s permitted a 0.5 s contraction phase and a 0.7 s passive recovery phase, i.e. an average of 25 contractions performed in 30 s. Peak torque, average torque, and the impulse produced in each contraction were recorded. The percent decline in torque over the 25 contractions was calculated and expressed as a fatigue index; the average of the best 3 of the first 5 or 6 contractions, and the final 3 contractions were used in the calculations.

2.5.5 Symptom limited maximal cycle ergometer exercise test

A progressive incremental exercise test to measure the maximal exercise capacity of each patient was performed using an electrically braked cycle ergometer (Siemens Elema 370) (Jones and Campbell, 1982). The initial workload was 100 kpm/min and the power output was increased by 100 kpm/min at the end of each minute. Maximal exercise capacity was defined as the workload at which the patient was unable to continue because of fatigue, symptoms, or because safety limits had been reached. In the current investigation the most important measure was maximal power output, therefore at the higher workloads the patients were allowed to remove the mouth-piece to ensure that unwillingness to breathe through this apparatus was not the primary reason for termination of the test. Subjects breathed through a low resistance, high velocity Hans Rudolph valve (Hans Rudolph, Kansas City, Mo.), and expired gas was analyzed continuously by a calibrated, automated exercise testing system (SensorMedics MMC Horizon, SensorMedics, Anaheim CA) for the measurement of ventilation (VE), oxygen intake ($\dot{V}O_2$) and carbon dioxide output ($\dot{V}CO_2$). Heart rate was monitored continuously using a 12 lead electrocardiogram (1515 - B Automatic Cardiograph, Hewlett Packard), and a recording was made at the end of each minute. Blood pressure was measured by auscultation at alternate workloads. Symptoms of leg effort, dyspnea, and chest pain were obtained at the end of each minute using the Borg rating category scale with ratio properties (Borg, 1982). None of the pre- training tests were terminated by the attending physician because of untoward clinical signs, or ECG changes suggestive of significant myocardial ischemia.

2.5.6 Submaximal exercise test

The purpose of this test was to measure the subject's endurance capacity, defined as the time to a Borg scale leg effort rating of 7, at 80% of the maximum power output achieved in the maximal progressive incremental exercise test. Subjects commenced cycling on an electrically braked cycle ergometer (Jaegar E\9) at an initial workload equivalent to 40% of their maximum power output for two minutes. This period served as a warm - up. Subsequently the workload was increased to 80% of the maximum attained during progressive incremental testing, and the subjects continued until they achieved a Borg scale leg effort rating of 7. Symptoms of leg effort, dyspnea, and chest pain were assessed at the end of each minute. Subjects announced, without prompting, if leg effort ratings of 4 and 7 were reached between minutes. Heart rate was monitored at rest, during each minute of exercise, and immediately following the completion of exercise. Standardized encouragement was provided throughout. Submaximal endurance capacity following the training was assessed at the same absolute workload as before training.

2.5.7 Stair climb

The purpose of this test was to assess the ability of the subject to undertake a physically demanding activity of daily living. The time to complete the climbing of 36, 20 cm, steps (4 flights) at the subject's normal rate of ascent was recorded. Subjects were allowed two practice trials prior to the recorded trial in an attempt to account for the influence of a learning effect. The Borg scale was used to obtain a subjective rating of the subject's leg effort rating, dyspnea, and chest pain. Heart rate was monitored by carotid artery palpation prior to, and immediately following the completion of each ascent. Standardized encouragement was provided throughout, and subjects were tested individually using an isolated stairway. Two testing bouts were performed on separate days.

2.6 Statistical analysis

Comparisons of pre- and post- measures were made within and between groups using either two- or three- way repeated measures analysis of variance (Kerlinger, 1973). Statistical significance was accepted at 5%. The Newman Keuls procedure was used to identify the location of specific differences when significant F values were found.

CHAPTER 3: RESULTS

3.1 Subject characteristics

Patients in the Aer and AerWt group were comparable with respect to age, height, weight, number of months in the Chedoke-McMaster Cardiac Exercise Rehabilitation Programme prior to the commencement of this study, myocardial infarction, coronary artery bypass graft surgery, and the use of beta-blockers, calcium blockers, nitrates, antiarrhythmics, diuretics, and pressor drugs (see Table 1). None of the patients developed any significant symptoms of myocardial ischemia during the study. One of 11 Aer voluntarily withdrew from the study. In addition, one AerWt patient had to suspend participation because of coronary artery bypass surgery and another AerWt patient did not complete post-training testing due to a family tragedy. Compliance in the study was defined as the completion of 20 sessions within 12 weeks. The data from subjects who did not fulfil this criterion were excluded from group analysis. Two Aer subjects and one AerWt subject were non-compliers.

Table 1: DESCRIPTION OF SUBJECTS BY AGE, HEIGHT, WEIGHT, MEAN NUMBER OF MONTHS IN EXERCISE REHABILITATION, DISEASE CATEGORIES, AND MEDICATIONS

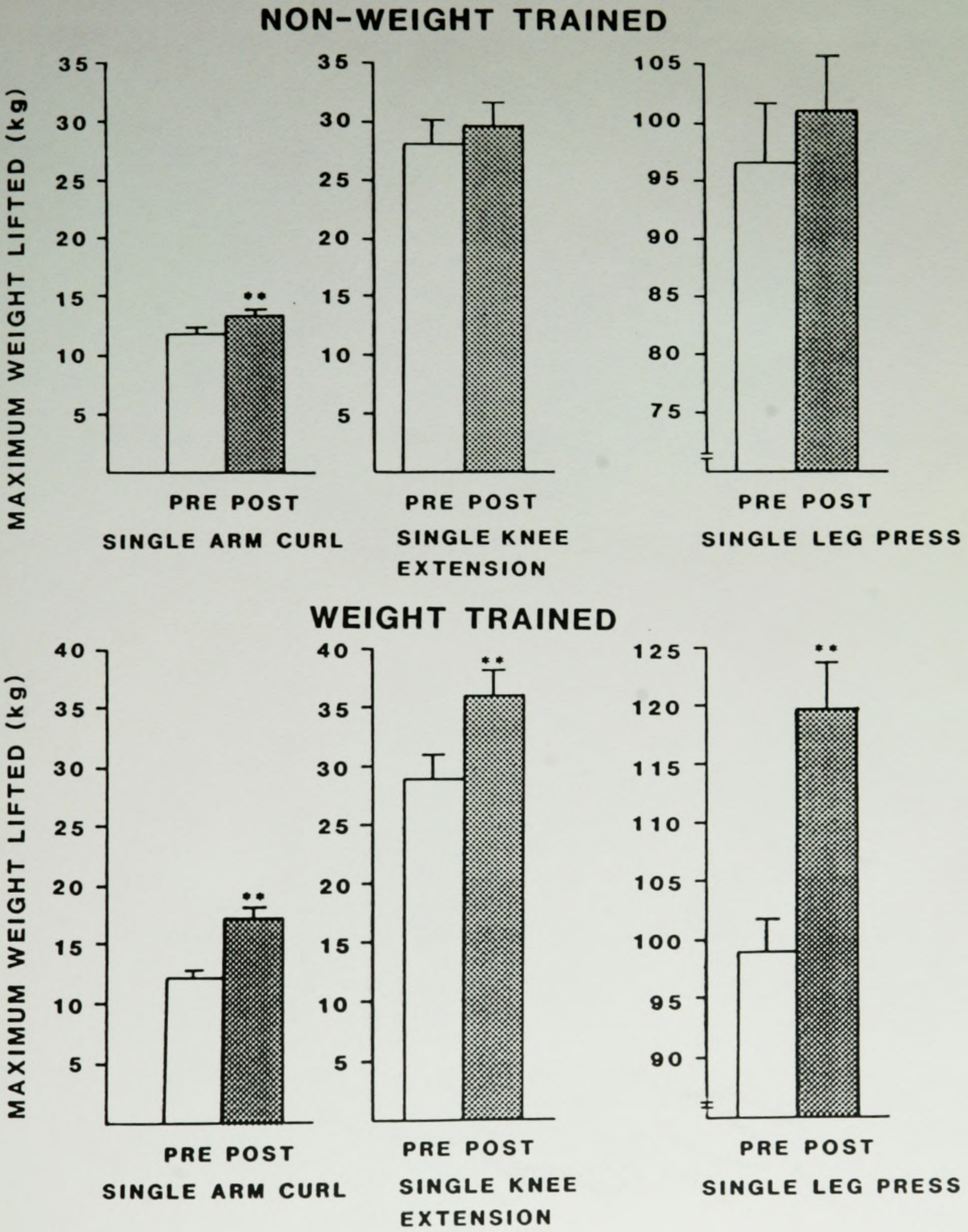
Detail	Aer group (n=8) ($\bar{x}$ ± S.E.M.)	AerWt group (n=10) ($\bar{x}$ ± S.E.M.)
Age	52 ± 3.2 years	49 ± 2.5 years
Height	175 ± 2.1 cm.	175 ± 1.2 cm.
Weight	Pre- 82 ± 3.7 kg. Post- 81 ± 3.5 kg.	Pre- 87 ± 3.6 kg. Post- 87 ± 3.4 kg.
Months in exercise rehabilitation	5.8 ± 1.2 months	5.4 ± 0.5 months
Myocardial infarction	7	10
Coronary artery bypass graft	0	2
Beta-blockers	4	6
Calcium-blockers	3	2
Nitrates	5	2
Anti-arrhythmics	0	0
Diuretics	1	2
Pressor Drugs	0	1

3.2 Effects of exercise training programme

3.2.1 Weightlifting strength

The one-repetition maximum strength (1RM) test was performed by all subjects before and after training in 3 of the 4 weightlifting exercises. The average increase in 1RM in the AerWt group for the single-arm curl, single-knee extension, and single-leg press exercises was 29%, compared to an average increase of 8% in the Aer group. In particular, the single-arm curl strength of the AerWt group increased by 42% ($\bar{x}$ ± S.E.M, 12.2, ± 0.6 to 17.4, ± 0.8 kg, $P < 0.01$), compared to a smaller gain in the Aer group of 13% which, however, was also significant (11.8, ± 0.5 to 13.3, ± 0.6 kg, $P < 0.01$, see Figure 3). In single-knee extension exercise there was a significant increase of 25% (28.9, ± 1.9 to 36.0, ± 2.2 kg., $P < 0.01$) in the AerWt group, compared to an increase of only 5.3% (28.2, ± 1.9 to 29.7, ± 1.9 kg., N.S., see Figure 3) in the Aer group. Similarly, the AerWt group demonstrated a significant increase in single-leg press strength of 21% (99.0, ± 2.8 to 119.7, ± 3.9 kg., $P < 0.01$), but there was a corresponding increase in the Aer group of only 5% (96.7, ± 4.9 to 101.1, ± 4.7 kg., N.S., see Figure 3).

Fig. 3: The 1RM in single-arm curl, single-knee extension, and single-leg press exercise, pre- (open bars) and post- (shaded bars) 10 weeks (20 sessions) of either aerobic endurance training, or combined aerobic and weightlifting training. * $P < 0.05$; ** $P < 0.01$.


NON-WEIGHT TRAINED
MAXIMUM WEIGHT LIFTED (kg)
35
30
25
20
15
10
5
**
PRE POST
SINGLE ARM CURL
35
30
25
20
15
10
5
PRE POST
SINGLE KNEE EXTENSION
105
100
95
90
85
80
75
PRE POST
SINGLE LEG PRESS
WEIGHT TRAINED
MAXIMUM WEIGHT LIFTED (kg)
40
35
30
25
20
15
10
5
**
PRE POST
SINGLE ARM CURL
40
35
30
25
20
15
10
5
**
PRE POST
SINGLE KNEE EXTENSION
125
120
115
110
105
100
95
90
**
PRE POST
SINGLE LEG PRESS

3.2.2 Weightlifting endurance

Post- training, all subjects attempted to successively lift their initial 1RM load as many times as possible. Averaging the single-arm curl, single-knee extension, and single-leg press exercises, the pre-1RM load was lifted 14 times by the AerWt group and 4 times by the Aer group. In more detail, the AerWt group lifted their pre-training 1RM load 14, ± 0.7 times in the single-arm curl, 9, ± 1.0 times in the single-knee extension, and 20, ± 2 times in the single-leg press exercises (see Figure 4). The corresponding numbers of repetitions in the Aer group were 4, ± 0.8, 2, ± 0.4, and 4, ± 0.6, respectively (see Figure 4).

3.2.3 Isokinetic strength

Post-training, neither group showed significant changes in the peak torque or impulse at any angular velocity in either the single-knee extension or single-leg press exercises (see Figure 5); the changes ranged from -13 to +3%, and from -1 to +8% in the Aer and AerWt groups, respectively [see Appendix G (ii)]. There was also no significant change in either group in the average torque in single-knee extension exercise at any angular velocity after training [see Appendix G (ii)]. In the single-leg press

Fig. 4: The maximum number of times post- training (shaded bars) that the initial 1RM (open bars) could be successively lifted in single-arm curl, single-knee extension, and single-leg press exercise, after 10 weeks (20 sessions) of either aerobic endurance training, or combined aerobic and weightlifting training.

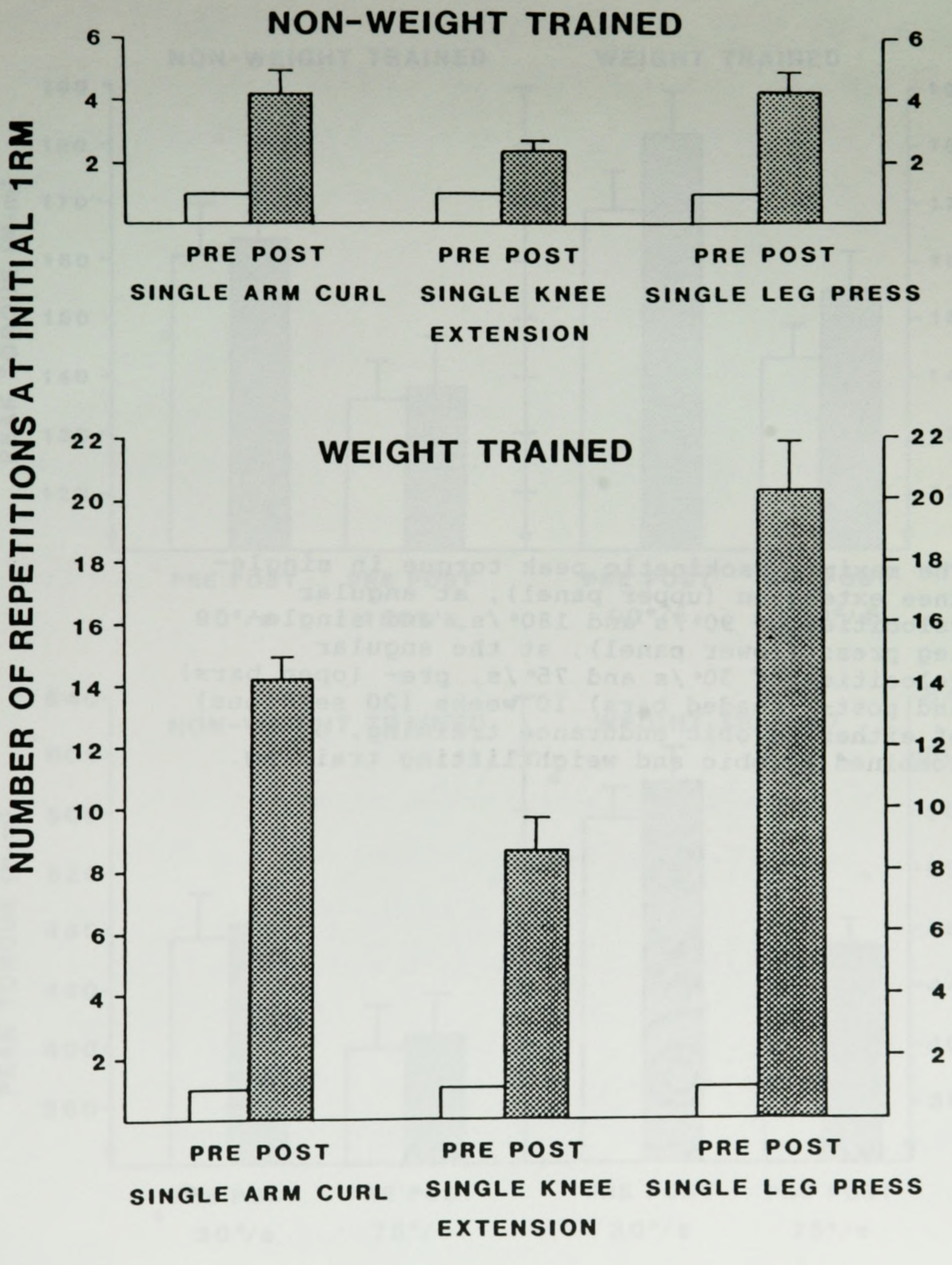
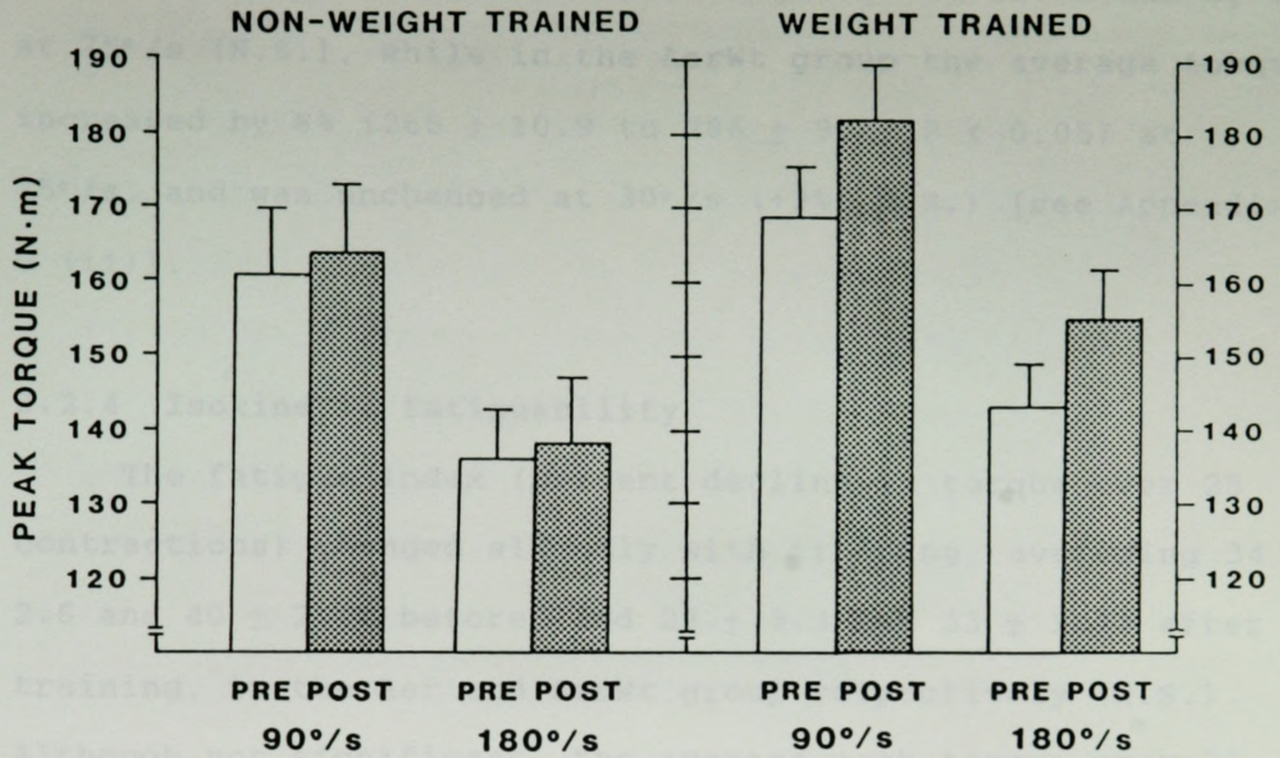
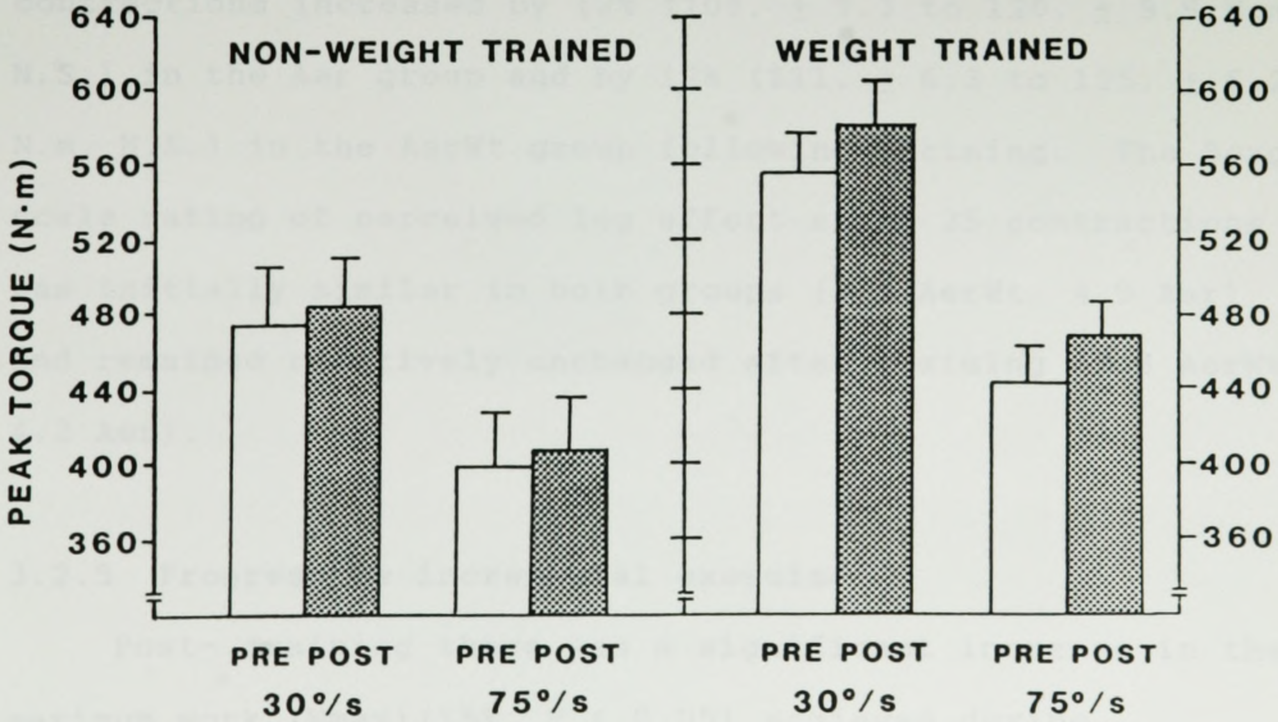

NON-WEIGHT TRAINED
WEIGHT TRAINED
NUMBER OF REPETITIONS AT INITIAL 1RM
6
4
2
22
20
18
16
14
12
10
8
6
4
2
PRE POST
SINGLE ARM CURL
PRE POST
SINGLE KNEE EXTENSION
PRE POST
SINGLE LEG PRESS

Fig. 5: The maximum isokinetic peak torque in single-knee extension (upper panel), at angular velocities of 90°/s and 180°/s, and single-leg press (lower panel), at the angular velocities of 30°/s and 75°/s, pre- (open bars) and post- (shaded bars) 10 weeks (20 sessions) of either aerobic endurance training, or combined aerobic and weightlifting training.


NON-WEIGHT TRAINED
WEIGHT TRAINED
PEAK TORQUE (N·m)
190
180
170
160
150
140
130
120
PRE POST
PRE POST
PRE POST
PRE POST
90°/s
180°/s
90°/s
180°/s


NON-WEIGHT TRAINED
WEIGHT TRAINED
PEAK TORQUE (N·m)
640
600
560
520
480
440
400
360
PRE POST
PRE POST
PRE POST
PRE POST
30°/s
75°/s
30°/s
75°/s

exercise the average torque in the Aer group decreased by 5% (306 ± 17.5 to 291 ± 15.2 N.m., $P < 0.05$) at 30°/s and by 4% at 75°/s (N.S.), while in the AerWt group the average torque increased by 8% (266 ± 10.9 to 286 ± 9.2, $P < 0.05$) at 75°/s, and was unchanged at 30°/s (+3%, N.S.) [see Appendix G (ii)].

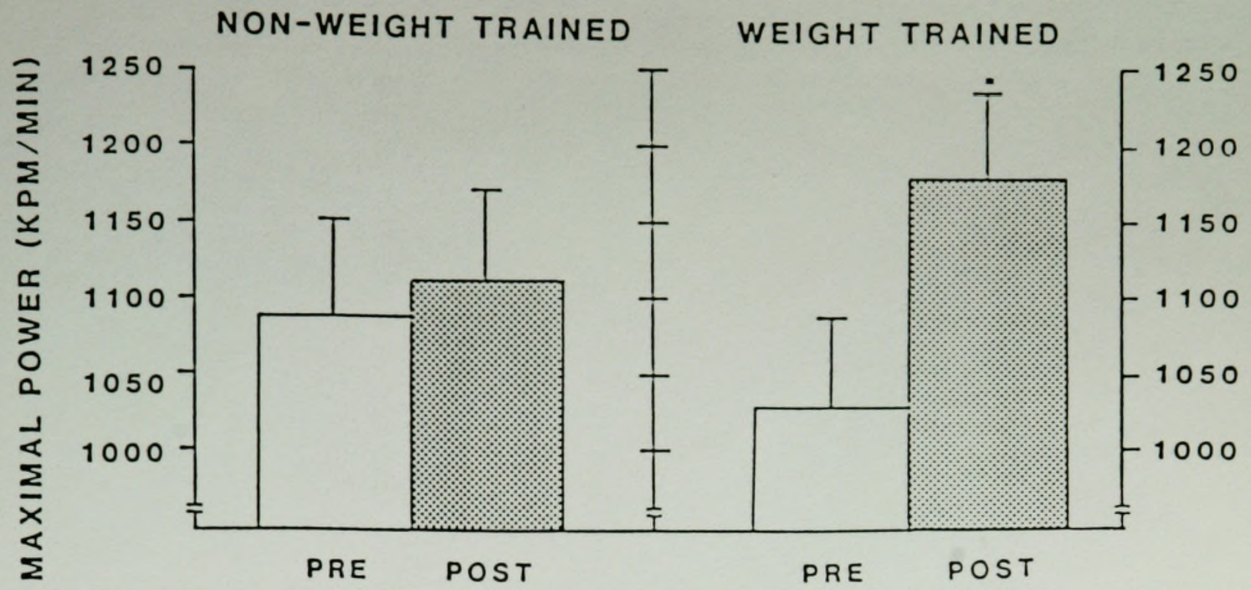
3.2.4 Isokinetic fatiguability

The fatigue index (percent decline in torque over 25 contractions) changed slightly with training, averaging 34 ± 2.6 and 40 ± 2.4% before, and 28 ± 3.3 and 33 ± 1.7% after training, in the Aer and AerWt group respectively (N.S.). Although not significant, the average peak torque over 25 contractions increased by 12% (108, ± 9.3 to 120, ± 9.9 N.m, N.S.) in the Aer group and by 12% (111, ± 6.3 to 125, ± 6.2 N.m, N.S.) in the AerWt group following training. The Borg scale rating of perceived leg effort after 25 contractions was initially similar in both groups (3.5 AerWt, 4.9 Aer) and remained relatively unchanged after training (2.3 AerWt, 4.2 Aer).

3.2.5 Progressive incremental exercise

Post- training there was a significant increase in the maximum work (Wmax)(15%, $P < 0.05$) achieved during progressive incremental cycle ergometer testing in the AerWt group, but no improvement (+ 2%, N.S., see Figure 6) in the Aer group. The effects of exercise training were the same when the values were expressed as percent predicted for a healthy control population. The AerWt group showed a significant increase from 83 ± 4 to 96 ± 3% ($P < 0.01$) of predicted Wmax, whereas there was only a small (N.S.) change in the Aer group (89 ± 3 to 92 ± 3%, see Figure 6). It was of interest that the Aer group showed minimal changes in both progressive incremental exercise capacity (Wmax) and weightlifting strength (1RM), whereas most of the AerWt group demonstrated improvements in aerobic power, and relatively similar increases in measures of lower limb strength (see Figure 7). At the higher submaximal cycling work loads (see Figure 8), and at set relative intensities above 50% of pre- training Wmax (see Figure 9) the mean rating of perceived leg exertion post- training was unchanged in the Aer group, but was lower in the AerWt group. At Wmax the mean rating of perceived leg exertion remained unchanged in both groups after training (see Fig 9).

Fig. 6: The maximal power output in progressive incremental cycle ergometry exercise expressed as absolute (upper panel) and as percent predicted for a healthy control population (lower panel), pre- (open bars) and post- (shaded bars) 10 weeks (20 sessions) of either aerobic endurance training, or combined aerobic and weightlifting training. * $P < 0.05$; ** $P < 0.01$.


NON-WEIGHT TRAINED
WEIGHT TRAINED
MAXIMAL POWER (KPM/MIN)
1250
1200
1150
1100
1050
1000
*
PRE
POST
PRE
POST

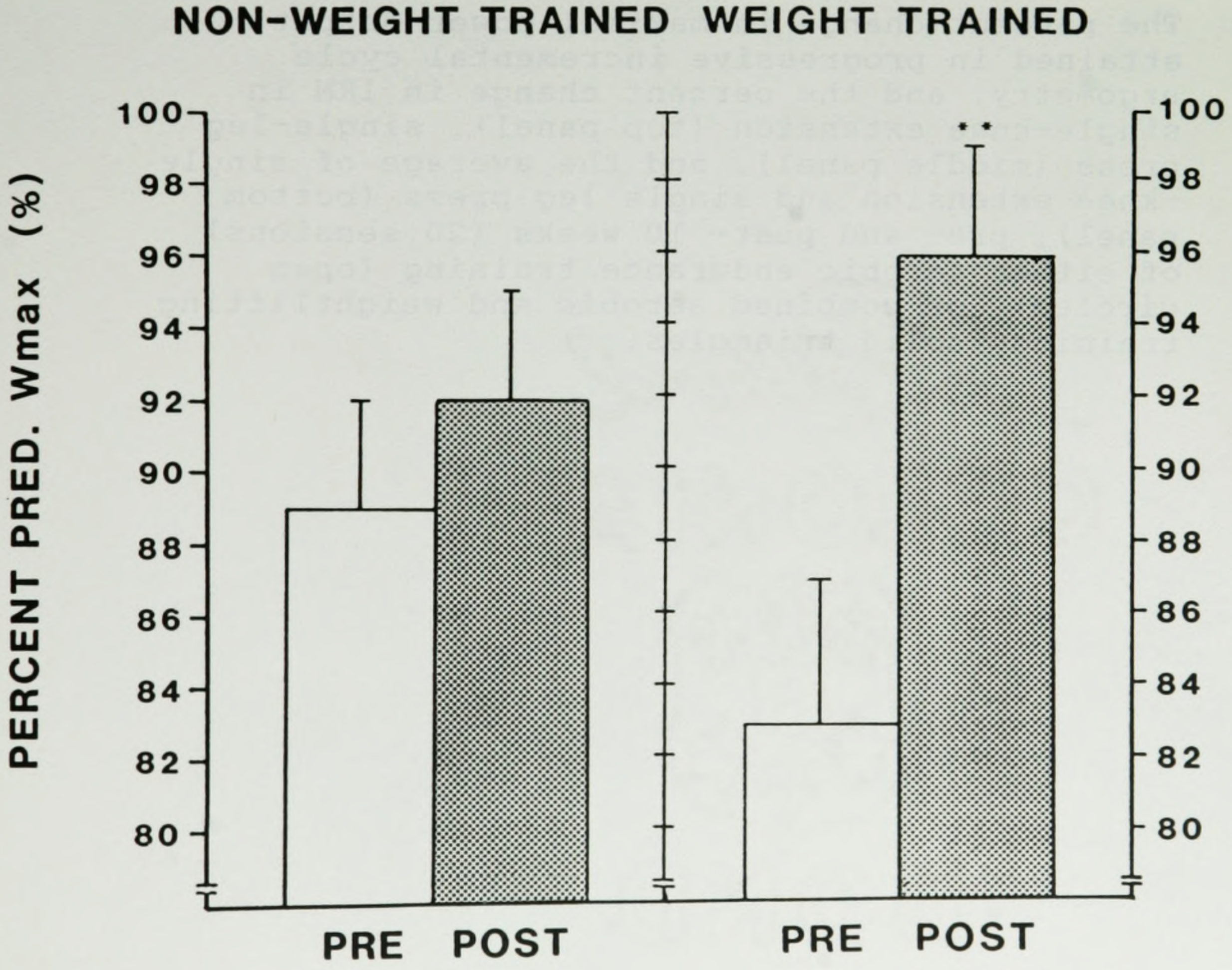
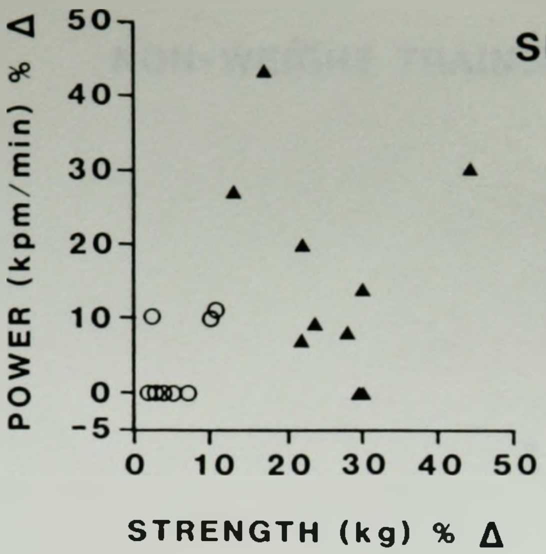
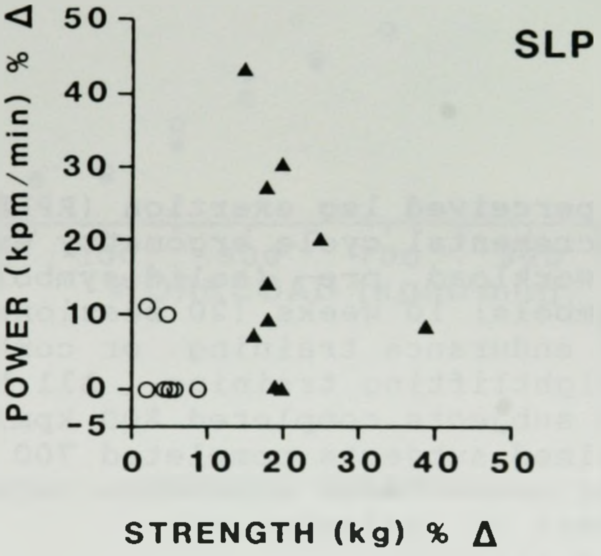

NON-WEIGHT TRAINED
WEIGHT TRAINED
PERCENT PRED. Wmax (%)
100
98
96
94
92
90
88
86
84
82
80
**
PRE
POST
PRE
POST

Fig. 7: The percent change in maximal power output attained in progressive incremental cycle ergometry, and the percent change in 1RM in single-knee extension (top panel), single-leg press (middle panel), and the average of single -knee extension and single-leg press (bottom panel), pre- and post- 10 weeks (20 sessions) of either aerobic endurance training (open circles), or combined aerobic and weightlifting training (solid triangles)


SKE
POWER (kpm/min) % Δ
STRENGTH (kg) % Δ
50
40
30
20
10
0
-5
0
10
20
30
40
50


SLP
POWER (kpm/min) % Δ
STRENGTH (kg) % Δ
50
40
30
20
10
0
-5
0
10
20
30
40
50

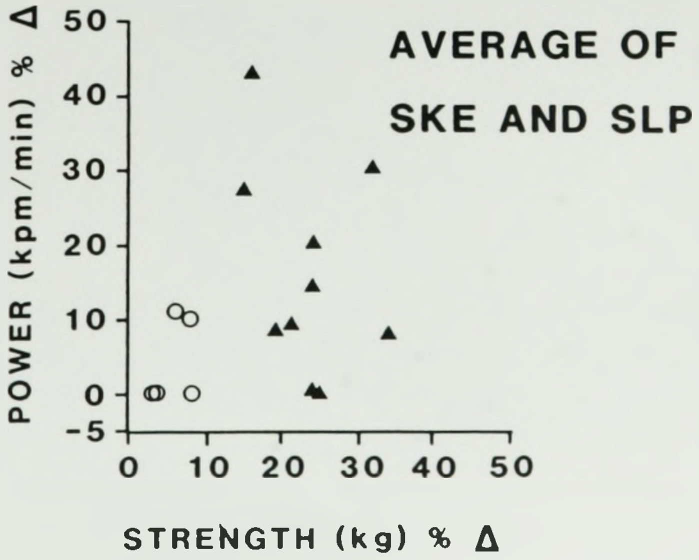
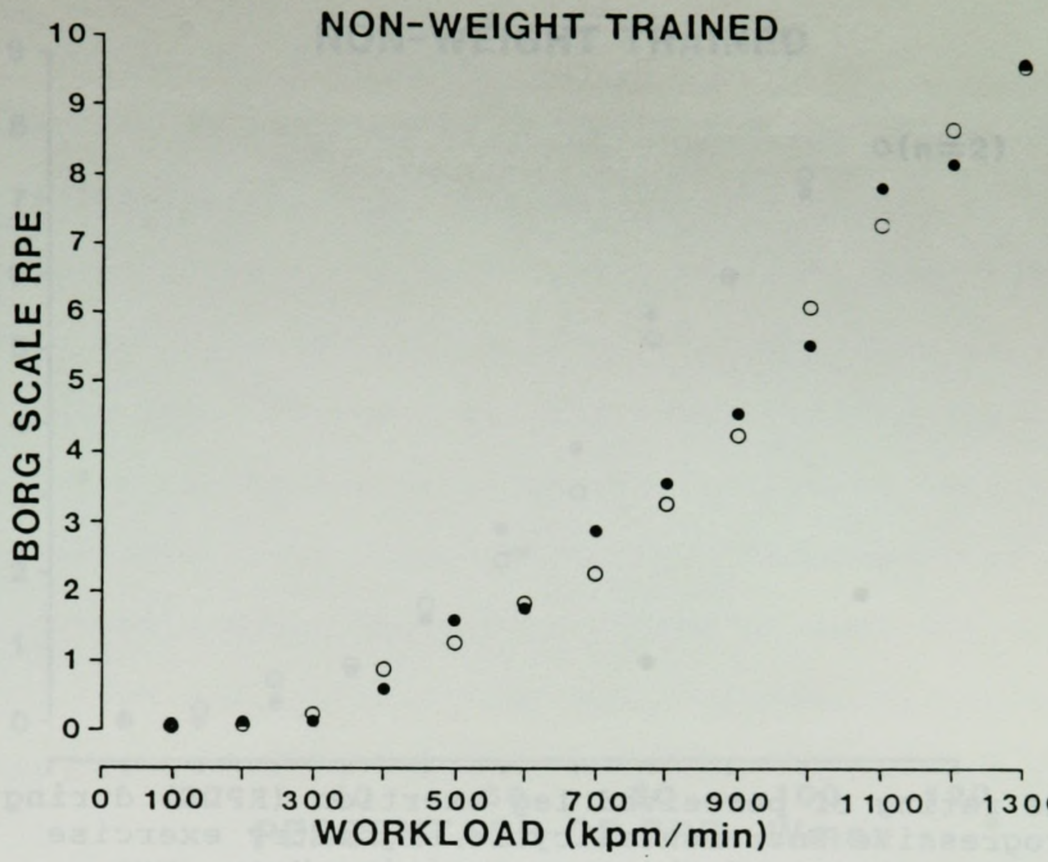

AVERAGE OF
SKE AND SLP
POWER (kpm/min) % Δ
STRENGTH (kg) % Δ
50
40
30
20
10
0
-5
0
10
20
30
40
50

Fig. 8: The rating of perceived leg exertion (RPLE) during progressive incremental cycle ergometry exercise at each absolute workload, pre- (solid symbols) and post- (open symbols) 10 weeks (20 sessions) of either aerobic endurance training, or combined aerobic and weightlifting training. All Non-weight trained subjects completed 800 kpm/min and all Weight-trained subjects completed 700 kpm/min. The data points above these workloads represent differing numbers of patients [see Appendix E (v) a)].


NON-WEIGHT TRAINED
BORG SCALE RPE
0
1
2
3
4
5
6
7
8
9
10
0
100
300
500
700
900
1100
1300
WORKLOAD (kpm/min)

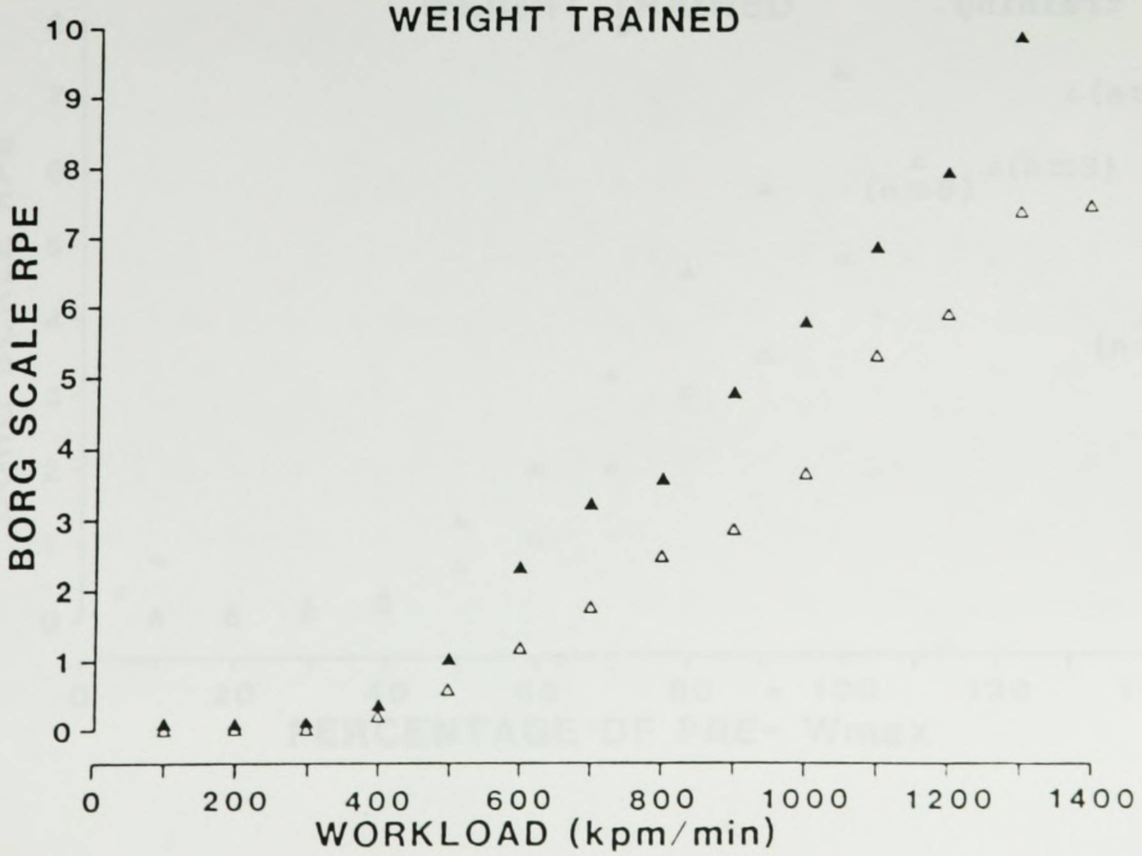
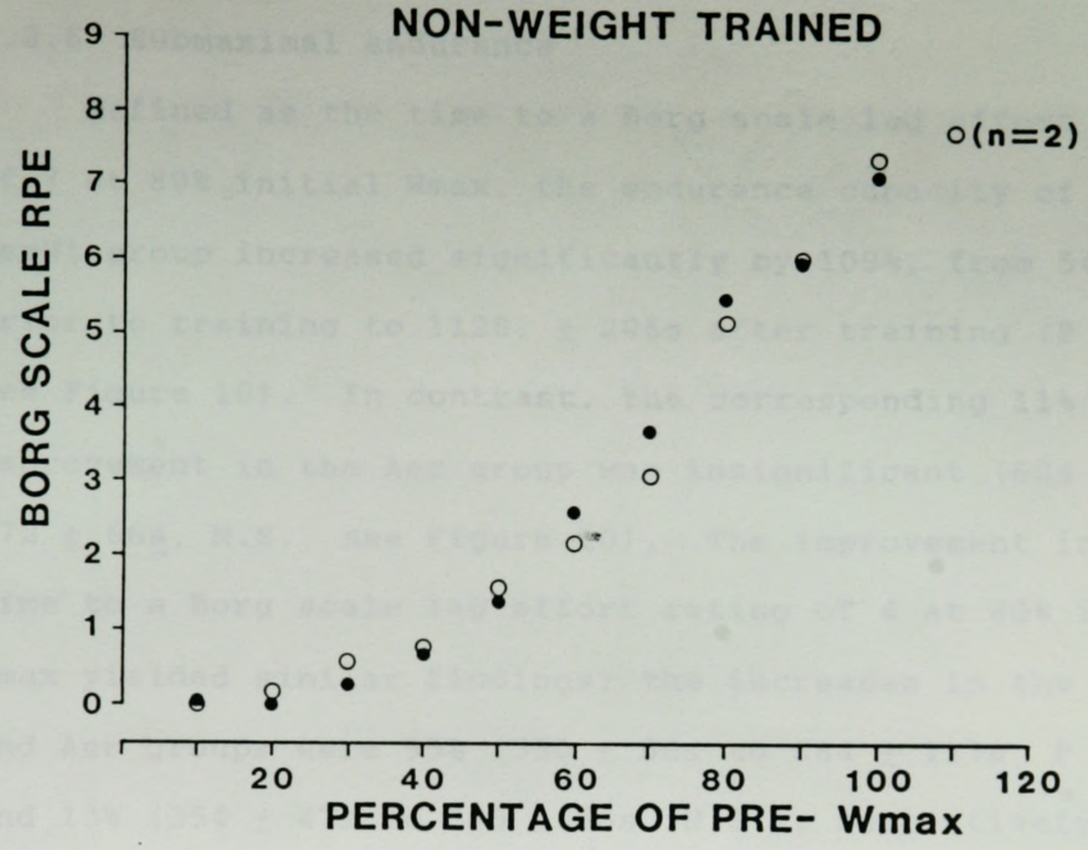
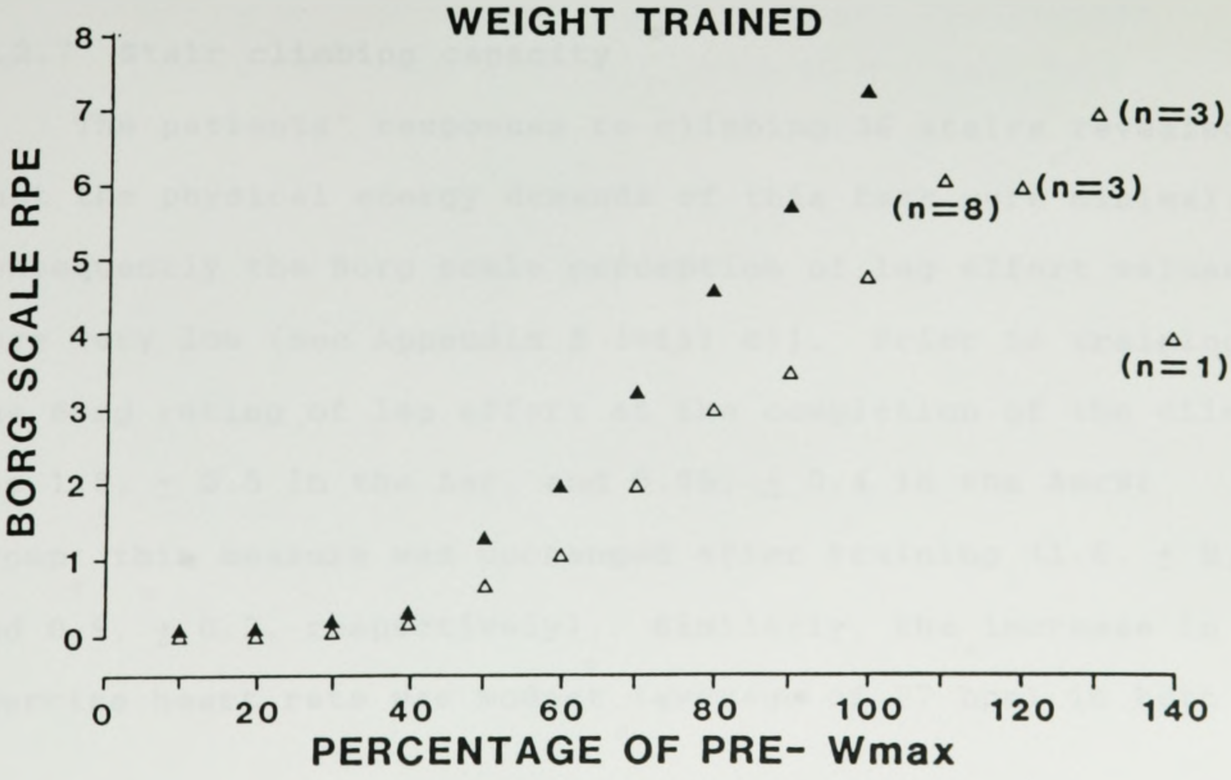

WEIGHT TRAINED
BORG SCALE RPE
0
1
2
3
4
5
6
7
8
9
10
0
200
400
600
800
1000
1200
1400
WORKLOAD (kpm/min)

Fig. 9: The rating of perceived leg exertion (RPLE) during progressive incremental cycle ergometry exercise at percentages of the pre- training Wmax, pre (solid symbols) and post- (open symbols) 10 weeks (20 sessions) of either aerobic endurance training, or combined aerobic and weightlifting training.


NON-WEIGHT TRAINED
BORG SCALE RPE
0
1
2
3
4
5
6
7
8
9
20
40
60
80
100
120
PERCENTAGE OF PRE- Wmax
○(n=2)


WEIGHT TRAINED
BORG SCALE RPE
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
140
PERCENTAGE OF PRE- Wmax
△(n=3)
(n=8)
△(n=3)
(n=1)

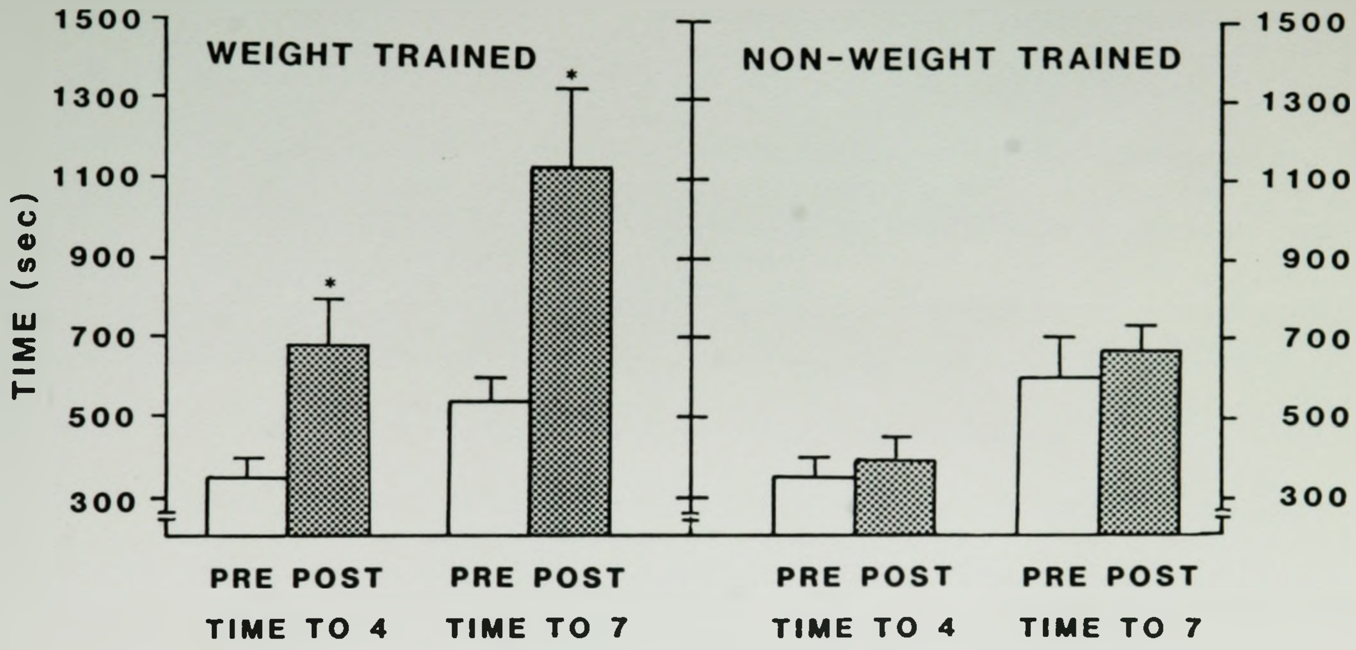
3.2.6 Submaximal endurance

Defined as the time to a Borg scale leg effort rating of 7 at 80% initial Wmax, the endurance capacity of the AerWt group increased significantly by 109%, from 541, ± 61s prior to training to 1128, ± 205s after training ($P < 0.05$, see Figure 10). In contrast, the corresponding 11% improvement in the Aer group was insignificant (604 ± 98s to 672 ± 66s, N.S., see Figure 10). The improvement in the time to a Borg scale leg effort rating of 4 at 80% initial Wmax yielded similar findings; the increases in the AerWt and Aer groups were 95% (350 ± 50s to 684 ± 117s, $P < 0.05$) and 13% (354 ± 47s to 399 ± 56s, N.S.), respectively (see Figure 10).

3.2.7 Stair climbing capacity

The patients' responses to climbing 36 stairs revealed that the physical energy demands of this task were minimal; consequently the Borg scale perception of leg effort values were very low [see Appendix E (vii) c)]. Prior to training, the Borg rating of leg effort at the completion of the climb was 1.5, ± 0.5 in the Aer, and 0.95, ± 0.4 in the AerWt group; this measure was unchanged after training (1.6, ± 0.6 and 0.9, ± 0.2, respectively). Similarly, the increase in exercise heart rate was modest (average of 27 bpm) in both

Fig. 10: Cycle ergometry time at 80% of the pre- training maximum power output before attaining a Borg RPE of either 4 or 7 for the legs, pre- (open bars) and post- (shaded bars) 10 weeks (20 sessions) of either aerobic endurance training or combined aerobic and weightlifting training,. * $P < 0.05$.


WEIGHT TRAINED
NON-WEIGHT TRAINED
TIME (sec)
1500
1300
1100
900
700
500
300
*
*
PRE POST
TIME TO 4
PRE POST
TIME TO 7
PRE POST
TIME TO 4
PRE POST
TIME TO 7

groups, and was not affected by training (N.S.)[see Appendix E (vii) b)]. For these reasons it was concluded that the intensity of the stair-climbing challenge was insufficient to reflect any change in the patients' increased physical work capacity following the intervention.

CHAPTER 4: DISCUSSION

4.1 Introduction

In recent years exercise training has become widely accepted as part of rehabilitation therapy for selected CAD patients. The purpose of prescribing exercise following a MI is to restore the patient to an optimal functional capacity appropriate to their lifestyle. To accomplish this goal cardiac exercise programmes have traditionally devoted a large portion of each exercise session to aerobic-endurance activities and have generally neglected muscular strength exercise. Only one recently published investigation has studied the effects of strength training as an additional mode of exercise, on the functional capacity of cardiac patients (Kelemen et al., 1986).

4.2 Purpose of the Present Investigation

The purpose of this thesis investigation was to evaluate the effectiveness of dynamic strength training as an additional mode of exercise rehabilitation, in patients with documented CAD and evidence of a previous MI.

4.3 Types of Exercise Training Used in the Physical Training of CAD Patients

4.3.1 Aerobic Endurance Exercise

Aerobic-endurance activities such as walking, jogging, cycling, swimming, and rowing are most often used in the physical training of cardiac patients. A regular dynamic exercise programme of this type is favoured in the rehabilitation of cardiac patients because it is associated with a decrease in HR and SBP at matched submaximal work loads, an increased functional capacity (Wmax) and $\dot{V}O_2$ max, and a more rapid recovery after an exercise bout (Clausen, Larsen and Trap-Jensen, 1969; Clausen and Trap-Jensen, 1976; Redwood, Rosing and Epstein, 1972; Vanauskas et al., 1966; Sanne, 1973; Hanson et al., 1968; Katila and Frick, 1970; Naughton, Bruhn, and Iategda, 1968; ; Rechnitzer et al., 1965; Seigal, Blomqvist, Mitchell, 1970; Skinner, Holloszy and Cureton, 1964). With this improvement in exercise efficiency, cardiac patients increase their ability to perform activities of daily living that primarily stress their cardiovascular systems. However, anecdotal evidence suggests that the peripheral muscle strength of CAD patients may often be inadequate to meet the demands of more strength and power oriented tasks.

A considerable degree of strength is needed to carry groceries, open windows, perform house maintenance, climb stairs, and to complete other routine activities of daily living. Many patients lack the physical strength to perform these common tasks comfortably, while others are physically strong enough to complete the tasks, but lack the confidence to attempt many of them. An increase in overall body strength may allow these patients to accomplish more physically demanding tasks, and thus improve the quality of daily life.

4.3.2 Dynamic Weight Training

4.3.2.1 Safety of dynamic weightlifting in CAD patients

Numerous investigations have shown that sustained static contractions in CAD patients are medically unacceptable due to the sharp rise in mean arterial pressure (MAP) and ventricular afterload that accompanies this mode of exercise (Fisher et al., 1973; Helfant, DeVilla and Meister, 1971; Kivowitz et al., 1971; Krayenbuehl, Rutishauser and Schoenbecle, 1972; Lind, 1970). Several studies have established the relative safety of weight carrying and lifting in selected MI patients (Kelemen et al., 1986; DeBusk et al., 1978; Markiewicz, Houston and DeBusk, 1979), but there is a lack of published information on both the circulatory responses to repeated weightlifting, and the appropriateness of this mode of exercise in CAD patients (Kelemen et al., 1986; Butler, Beierwaltes and Rodgers, 1987; Haslam et al., 1988; Vander et al., 1986).

In one study of the acute hemodynamic and ECG responses of CAD patients to resistance exercise Butler et al. (1987) reported no arterial pressure increase with upper extremity circuit weight training exercise done on pneumatic resistance machines at 40 -60% 1RM, and other work (Vander et al., 1986) reported only slight arterial pressure increases with lifting exercises of comparable relative intensity on Nautilus machines. Similarly, Keleman and colleagues (1986) reported that moderate intensity (40% 1RM) circuit weight training in cardiac patients was associated with only small elevations in arterial pressures. All three investigations concluded that low resistance, full range of motion strength conditioning, was appropriate in selected CAD patients (Kelemen et al., 1986; Butler, Beierwaltes and Rodgers, 1987; Vander et al., 1986).

Only one study, however, has examined the intra-arterial pressures and ECG responses in MI patients during progressive resistance weightlifting exercise (Haslam et al., 1988)(see Appendix A). The results of this investigation indicated that double-leg press at less than 60% 1RM, and single-leg press at less than 80%, elicited a maximal rate-pressure product (RPP) that did not exceed the value calculated at 85% of Wmax in cycle ergometer testing. As with the above studies, weightlifting did not precipitate any adverse ECG changes, or symptoms of angina pectoris in any of the patients. It was concluded that weightlifting exercise which utilized up to 15 repetitions and a resistance less than 80% of maximum, resulted in clinically acceptable ECG and arterial pressure responses in selected patients with CAD and evidence of a previous MI.

4.3.2.2 Efficacy of weight training in CAD patients

A single published study has investigated the effects of dynamic weight training as an additional mode of exercise in the rehabilitation of cardiac patients (Keleman et al., 1986). This prospective randomized trial employed the resistance training approach of circuit weight training (Gettman et al., 1978); the exercise regimen was done 3 times a week for 10 weeks, with loads set at 40% 1RM. The circuit training protocol involved 2 circuits of 10 to 15 repetitions of 6 upper body, and 2 lower body exercises, with 30s rest between each set of lifts; a walk\jog component was also included in each exercise session (Kelemen et al., 1986). Control patients completed the walk\jog exercise, but participated in low intensity recreational games instead of the weightlifting exercise.

Post- training, the overall weightlifting strength of the experimental group increased significantly by an average of 24%, while control group strength remained unchanged (Kelemen et al., 1986). This improvement in strength is comparable to investigations that have studied the effects of circuit weight training in healthy individuals (increases in strength ranging from 20 to 44%) (Gettman et al., 1978; Allen, Byrd and Smith, 1979; Gettman et al., 1979; Gettman, Ward and Hagan, 1982; Hurley et al., 1984; Wilmore et al., 1978).

In addition to the gains in strength, the experimental group showed an increase of 12% in the time to exhaustion in a symptom limited stardard Bruce treadmill test, but there was no change in the control subjects (Kelemen et al., 1986). This increase in aerobic endurance capacity after circuit weight training was comparable to the results of similar studies in healthy subjects (Wilmore et al., 1978; Kimura, Itaw, and Yamzaki, 1981).

Although the gains in strength and treadmill endurance time of the circuit weight training patients in the Kelemen et al (1986) study were significant, these improvements resulted from a strength training protocol that recruited a relatively low percentage of the patients' maximum strength. Studies of both healthy young (Berger, 1962; Dons et al., 1979; McDonagh and Davies, 1984) and old (Vandervoort, Hayes and Belanger, 1986) subjects have indicated that in strength training programmes of equivalent frequency and duration, improvements in strength are related to the training intensity. Thus, in a strength training program of higher intensity, greater improvements in strength and functional capacity might be expected. Moreover, the treadmill method of exercise testing used by Keleman et al (1986) to measure aerobic endurance capacity probably did not specifically challenge the trained lower limb muscles. This is highlighted by the results of a study on the effects of strength training on the aerobic power of healthy subjects (Hickson, Rosenkoetter and Brown, 1980), which demonstrated an increase in the time to exhaustion during cycle ergometer exercise that was four times greater than during treadmill running. These investigators concluded that in order to accurately measure the increase in endurance capacity after resistance training, those muscles which were most directly involved during the training programme must be tested. The quadriceps muscles are responsible for the majority of work performed during cycling exercise; thus, with an emphasis on increasing the strength of the thigh muscles and the use of cycle ergometer exercise testing to specifically challenge those muscles, greater improvements in endurance performance might be expected.

4.4 Response of CAD Patients to Exercise Training in the Present Investigation

4.4.1 Weightlifting protocol

Comparisons of dynamic strength training studies in healthy subjects indicate that the greatest gains in muscle strength result from a programme of progressive resistance exercise done at high intensity and with relatively few repetitions, as first described by Delorme (1951). Compared to the high repetition low resistance circuit weight training regimen used by Kelemen and colleagues (1986), the current study used fewer repetitons and higher resistances, in an attempt to produce greater gains in strength and functional capacity (McDonagh and Davies, 1984).

A weight training schedule comprising 3 to 5 sets with

8RM to 12RM loads, done 2 or 3 times per week, is considered to promote the greatest increases in muscle strength in healthy young (Gonyea and Sale, 1982) and older men (Vandervoort, Hayes and Belanger, 1986). The present study incorporated loads of a somewhat lower intensity (see Appendix C), based on our previous observations in CAD patients that weightlifting exercises which utilized relatively few repetitions and a resistance less than 80% 1RM resulted in clinically acceptable circulatory changes (Haslam et al., 1988). The increased risk of orthopedic and cardiac events associated with higher intensity weight training was considered unacceptable for the purposes of this thesis.

4.4.2 Changes in dynamic weightlifting strength

A major finding of the present investigation was the large increase in dynamic weightlifting strength (1RM) in the experimental group. The mean increase in the single-arm curl 1RM (42%) was similar to the change observed in healthy young and older subjects after a similar training protocol (Moritani and de Vries, 1979 and 1980), and in healthy older subjects following training at a higher relative intensity (80% 1RM)(Brown et al., 1988). Similarly, the mean improvement (23%) in lower limb 1RM performance in the AerWt group was comparable to the gains reported for young men in several traditional weightlifting studies (Hurley et al., 1984; Pipes and Wilmore, 1975), but was less than in studies of comparable duration, but which used loads of >80% of maximum (Hickson, Rosenkoetter and Brown, 1980; Allen, Byrd and Smith, 1976; Dons et al., 1979; Thorstensson et al, 1976; Kanakis and Hickson, 1980; Rutherford et al., 1986; Wilmore, 1974). Compared to progressive weight training studies in healthy older male subjects the mean increase in lower limb 1RM in the AerWt group was similar to the average increase of 30% reported by Brown et al. (1988), but considerably less than the extraordinary increase of 167% reported by Frontera et al. (1988), following 12 weeks of training at >80% of maximum. The increase in 1RM in the AerWt group was similar to the increase in the circuit weight training study of Kelemen et al. (1986), but the improvement occurred after only 20 training sessions, compared to 30 sessions in the Kelemen et al. study (1986). It would appear that weightlifting training in CAD patients results in increases in strength which are qualitatively similar to those in healthy subjects.

The increase in strength observed in the AerWt group may be attributed to several physiological adaptations. Investigators in a previous weightlifting study involving healthy subjects of similar ages attributed the strength gains exclusively to a neural adaptation, since gross estimates of muscle size did not change (Moritani and deVries, 1979 and 1980). Several recent studies however, have reported significant increases in muscle cross-sectional areas, assessed by computed tomography, and increases in individual muscle fiber size (Brown et al., 1988; Frontera et al., 1988) after 12 weeks of weight training in older men. These investigators concluded that the morphological changes had indeed contributed to the observed increase in muscular strength. The subjects in those studies however, trained at a greater relative intensity (>80% 1RM) and frequency (3 times per week) over a longer period (12 wks) than the AerWt patients in the present study. Therefore it seems less likely that similar morphological adaptations would have occurred in the AerWt patients, but in the absence of conclusive evidence this remains a possibility. The improvement in dynamic weightlifting strength in the AerWt patients after training is more likely the result of an increased ability to fully recruit their muscles during maximal testing on the training devices. This proposed increase in motor unit activation has been suggested by other investigators, who observed similar changes in strength after a relatively short period of weightlifting training in healthy young (Thorstensson, 1976 and 1977) and older men (Moritani and deVries, 1979 and 1980), and in patients with neuromuscular disorders (McCartney et al., 1988).

4.4.3 Changes in isokinetic strength

The variation of the maximal force developed by muscles during contractions at different speeds is well documented (Perrine and Edgerton, 1978; McCartney et al, 1983a; 1983b; 1985). In the isokinetic measurement technique the controlled variable is the angular velocity of the instrument's lever arm and not the resistance, whereas in dynamic muscle strength testing the velocity becomes a consequence of the load applied on the muscle (Thorstensson, Grimby and Karlsson, 1976). The techniques employed in the present investigation have been used in other studies to measure isokinetic knee-extension (Thorstensson and Karlsson, 1976; Thorstensson, 1976; Thorstensson et al., 1976) and leg-press strength (Vandervoort, Sale and Moroz, 1984; Pipes and Wilmore, 1975), and muscle fatigue (Thorstensson, 1976).

Both the Aer and AerWt group demonstrated a small (N.S.) increase in knee extension and leg press peak torque after 10 weeks of training. In other studies the changes in isokinetic strength performance following dynamic weightlifting training have been inconsistent. Some studies have reported no change in the isokinetic strength of healthy young (Pipes and Wilmore, 1975) and older (Brown et al., 1988) men, while others have reported significant increases (Frontera et al., 1988; Thorstensson, 1977).

The concept of specificity of training maintains that improvement should be the greatest when strength is measured with a device that approximates the training procedure (Pipes and Wilmore, 1975; Berger RA, 1962; Coyle et al., 1981; Rasch PJ and Morehouse LE, 1957). It was not entirely unexpected, therefore, that in the present study the increase in dynamic weightlifting strength (1RM) in the AerWt group was much greater (approximately 4 times) than the gain in isokinetic strength (7%) (Fahey and Brown, 1973; Sale and MacDougall, 1981). This response may be attributed to a neural adaptation that is specific to the type of training (Komi et al., 1978). Strength training studies in healthy subjects have shown specificity of strength gain for both the type of contraction (Dons et al., 1979; Duchateau and Hainaut, 1984) and the velocity of movement (Frontera et al., 1988; Coyle et al., 1982; Caiozzo, Perrine and Edgerton, 1981; ; Sale, 1986).

Muscle fatigue was asssessed following 25 repeated maximal single-knee extensions performed at 180°/s on an isokinetic dynamometer (Cybex, Lumex N.Y.). Traditionally, 50 contractions are performed in such a fatigue test (Thorstensson and Karlsson, 1976), but the cirulatory response to this exertion in CAD patients is unknown. Thus, in order to minimize the risk of cardiovascular complications the number of contractions was reduced to 25. In the initial testing the fatigue index after 25 contractions (40%) in the AerWt group was comparable to that observed in healthy young males following 50 contractions, and was only slightly less (33%, N.S.) after training (Thorstensson, 1976). This again serves to emphasize the concept of specificity of training.

4.4.4 Changes in Maximum Exercise Capacity

The present study utilized a symptom limited maximum progressive incremental cycle ergometer test (Jones and Campbell, 1982) to measure the change in Wmax of all patients following the intervention. In studies of physical power and adaptation to exercise the cycle ergometer is used extensively as a testing instrument for various reasons. The magnitude of the external work can be expressed exactly, and reproduced with a greater degree of accuracy than in other types of exercise, and for the most part the mechanical efficiency is independent of body weight (Jones & Campbell, 1982; Astrand and Rodahl, 1986).

A major finding in the present study was that the mean Wmax in the AerWt group improved significantly by 15% after the intervention, compared to only a 2% (N.S.) increase in the control group. This change in aerobic power in the AerWt subjects is comparable to the gains in $\dot{V}O_2$ max observed in healthy sedentary middle-aged and older men (average of 17 to 20%) after aerobic endurance training of similar duration (Pollock et al., 1971; Saltin et al., 1969; Schocken et al., 1983), and in many studies of CAD patients (Detry and Bruce, 1971; Detry et al., 1971; Hung et al., 1984; Paterson et al., 1976; Froelicher et al., 1984; Kavanaugh et al., 1973; Oldridge et al., 1988). Moreover, the gain in Wmax in the AerWt group (15%) was slightly greater than the 12% increase in the mean treadmill time to exhaustion recorded by Keleman et al. (1986) after circuit weight training in CAD patients.

Several variables influence the magnitude of the increase in $\dot{V}O_2$ max and Wmax following dynamic exercise training. These include the pre-training level, the intensity and duration of training and the age of the subjects (Saltin et al., 1968; Hartley et al., 1969; Pollock, 1973). In CAD patients there are additional considerations of clinical status, left ventricular function, medications, and the elapsed time since the myocardial infarction (Franklin, Wrisley and Johnson, 1984). The absence of any change in Wmax in the Aer group, and the relatively modest increase in the AerWt group in the current study is probably a reflection of several of these factors: 1. compared to predicted values for healthy males of similar age, the initial level of Wmax in both groups was quite high at 89% and 84% of predicted, respectively; 2. the patients had participated in a supervised cardiac exercise programme for an average of 5.5 months prior to this study, and it is well documented that the major gains in $\dot{V}O_2$ max occur during the first 6 months of training (Sanne, 1973; Paterson et al., 1979); 3. the intensity of the aerobic training was moderate, and the number (20) of sessions was limited. Improvement in aerobic capacity with endurance exercise training has been shown to correlate positively to the conditioning intensity, frequency, and duration (Franklin, Wrisley, and Johnson, 1984). Hence the most impressive gains in $\dot{V}O_2$ max in CAD patients were attained after programmes of much higher intensity, and longer duration, than in the present investigation (Kasch and Boyer, 1969; Ehsani et al., 1982; Ehsani et al., 1981; Hagberg, Ehsani, and Holloszy, 1983).

4.4.5 Relationship of increased strength to improved Wmax in the present investigation

The inevitable effects of physiological aging will have caused some loss of strength in the CAD patients in the present study (Grimby and Saltin, 1983; Larsson, 1982; Larsson, Grimby and Karlsson, 1979). Strength decline with age however, is also related to disuse muscle atrophy, particularly of type II fibers, but this may be overcome by training (Larsson, 1982). It is possible that the reduction in physical activity of cardiac patients after a myocardial infarction may lead to a rapid decline in the function of type II fibers, and an associated decline in muscular strength (Oldridge et al., 1988). This being the case, it seemed possible that a strenuous program of resistance training might be capable of significantly increasing the strength of the patients in this study to levels where Wmax might be improved.

The relative contribution of an improvement in skeletal muscle strength and power to an increase in the exercise tolerance of CAD patients has recently been discussed by Oldridge et al. (1988). Following a period of heavy endurance training on a cycle ergometer these investigators observed an 18% increase in Wmax during progressive incremental cycle ergometry. This was associated with increases of 14% and 11% in the maximal peak power and total work, respectively, generated during 30s of maximal isokinetic cycling. The similar increase in Wmax and maximal muscle power prompted the authors to suggest that improved skeletal muscle power may have been an important contributor to the increased exercise tolerance of the cardiac patients (Oldridge et al., 1988). A major finding in the present study is that the relationship between the changes in strength (1RM) and exercise capacity (Wmax) of the AerWt patients following training supports this contention (see Figure 7). Most of the AerWt group demonstrated improvements in aerobic power, and similar increases in measures of lower limb strength, whereas the Aer group showed minimal change in both lower limb strength and Wmax. In a recent investigation of the relationship between Wmax and short-term maximal isokinetic power output, McCartney et al. (1988) provided evidence which suggested that weak lower limb strength may compromise the performance of CAD patients in progressive incremental exercise testing. Based on these findings, it seems likely that in the present study those patients who improved both their aerobic capacity and their lower limb strength after the training, were 1. limited in the initial progressive incremental test in part by peripheral muscle weakness, and that 2. following training an improvement in leg strength contributed to the increase in progressive incremental performance. This is an important finding because it has shown that strength training can effect large increases in aerobic work in a population who are supposed to be limited primarily by myocardial insufficiency.

The finding that CAD patients who were probably limited in progressive incremental exercise by peripheral muscle weakness may improve their aerobic work performance by increasing lower limb strength, has implications for the rehabilitation practitioner. In the past, traditional cardiac exercise rehabilitation has not specifically addressed the peripheral muscle strength of CAD patients, and weightlifting training for CAD patients has been contraindicated. The results of the present investigation suggest that in order for a CAD exercise rehabilitation programme to most effectively improve the functional capacity of CAD patients, the exercise regimen should incorporate a carefully monitored strength training component in conjunction with aerobic endurance training. Moreover, it seems probable that patients whose muscle strength is reduced, would benefit more from such a comprehensive approach than from aerobic exercise alone.

Two of the AerWt subjects achieved an identical absolute power output during maximal cycle ergometry before and after training, but increased their lower limb strength by an average of 25% (see Figure 7). This may support the proposition (McCartney et al., 1988) that in CAD patients with a high degree of leg strength the limiting factor in progressive incremental exercise is probably poor cardiovascular function.

4.4.6 Changes in the rating of perceived exertion during incremental exercise

A category scale with ratio properties developed by Borg (1982) to obtain a rating of perceived exertion (RPE) is used extensively in the graded exercise testing of healthy subjects and CAD patients (American College of Sports Medicine, 1986). Numbers are anchored by verbal expressions which are placed on a ratio scale according to their quantitative meaning (Borg, 1982). A major advantage of the Borg scale is that interindividual comparisons between measurements of subjective physical strain can be made in applied studies (Borg and Noble, 1974; Ekblom and Goldbarg, 1971; Gutmann et al., 1981).

In the present investigation the rating of perceived leg exertion (RPLE) was recorded during maximum progressive incremental cycling exercise before and after the 10 weeks of training. Figures 9 and 10 portray the mean RPLE obtained before and after training at each absolute workload, and at set percentages of the pre-training Wmax, respectively. An important observation was that at the higher submaximal work loads (Figure 8) and at relative intensities above 50% of initial Wmax (Figure 9) the mean RPLE was lower after the training in the AerWt group, but was unchanged in the Aer group. In both groups the RPLE at maximum work remained unchanged after the intervention (Figure 9). These findings are consistent with previous studies on the effects of training on exercise RPLE in healthy young men (Ekblom and Goldbarg, 1971) and in cardiac patients (Gutmann et al., 1981). A more detailed examination of Figure 9 shows that the degree of reduction in RPLE at each workload following training increased with increasing exercise intensity beyond approximately 50% of the initial Wmax.

Numerous factors are responsible for the patient's RPLE during exercise (Cafarelli, 1982). Factors which contribute directly to the intensity of the perceived leg exertion rating include: peak tension; the duration and frequency of contraction; muscle length, and the extent and velocity of muscle shortening; and lower limb muscular strength (Cafarelli E, 1977). During cycle ergometry most of these factors are controlled, thus perceived exertion is largely a function of the strength and metabolic condition of the lower limb musculature (Cafarelli, E; Kostka and Cafarelli, 1982). In the present study the lower RPLE in the AerWt patients at the same absolute workload, and at the same percentage of initial Wmax following training, may be attributed to an improved lower limb strength and the concomitant increase in Wmax. With the increase in muscle strength after training, any given absolute submaximal workload would require a lower percentage of the increased lower limb strength capacity, and thus would be perceived as less of a strain. Factors which affect local muscle metabolism have also been reported to contribute to the sensation of effort during sustained force output

(Kostka and Cafarelli, 1882). However, the possibility of such changes contributing only to the AerWt group RPLE response is perhaps unlikely.

The decrease in the rating of perceived exertion at the higher submaximal workloads, and at workloads greater than 50% of initial Wmax in the AerWt group after training, is a particularly important finding as it may improve the patients' quality of life. After training these patients may be able to perform strenuous activities of daily living with a reduced perception of effort, and with greater confidence and enjoyment.

4.4.7 Submaximal exercise performance

In the current study, submaximal endurance was defined as the time to a RPLE of 7 during cycling at a power output corresponding to 80% of initial Wmax. This time increased in both the Aer (11%, N.S.) and AerWt (109%) groups, but only the AerWt group achieved a statistically significant improvement ($P < 0.05$). The 109% improvement in the endurance capacity of the AerWt patients with training was greater than the large increase in cycle ergometer endurance time recorded in healthy young men after heavy resistance weight training by Hickson et al., (47%)(1980). This may support the concept that the leg muscles of CAD patients are often unusually weak and deconditioned. The enhanced submaximal endurance of the AerWt group probably reflects the attenuation of the RPLE observed at the higher percentages of initial Wmax during progressive incremental exercise after training (see Figure 9). The reduction in the perception of leg effort at a similar workload (80% of initial Wmax) following training probably allowed the AerWt group to exercise for a much longer period of time at this power output before symptoms of leg discomfort became limiting. Most domestic and occupational tasks demand less than a maximal effort, therefore the observed decrease in perception of effort during submaximal exertion may translate into improved function in many activities of daily living. It may be suggested that the AerWt patients would be able to perform the same submaximal tasks with less sensation of effort and for a longer duration after the training.

CHAPTER 5: SUMMARY AND RECOMMENDATIONS

5.1 Introduction

The purpose of this chapter is to summarize the present thesis investigation and to propose recommendations for future study.

5.2 Summary

Traditional cardiac exercise rehabilitation programmes have generally neglected muscular strength exercise. However, strength training may expose the patient to a type of physical stress that is not inherent in aerobic exercise. The purpose of this study was to evaluate the effectiveness of dynamic strength training as an additional mode of exercise rehabilitation, in patients with coronary artery disease and documented evidence of a previous myocardial infarction. The substantive hypothesis stated that subjects in the weightlifting + aerobic training group who were not obviously limited by impaired cardiovascular function would demonstrate greater improvements in tests of muscle strength and endurance capacity than aerobic trained control subjects.

Subjects for the present study were eighteen males who had been participating in the Chedoke-McMaster Cardiac Exercise Rehabilitation Programme. Following initial testing, subjects were stratified according to the length of their participation in the rehabilitation programme and their lower limb strength capacity (one repetition maximum (1RM) and isokinetic maximum voluntary performance). Subjects were then randomly assigned to either an aerobic training (Aer) (n=8), or weightlifting plus aerobic training (AerWt) (n=10) group. Both the Aer and AerWt groups completed two sessions a week for ten weeks (20 sessions).

In the AerWt group each session was comprised of a warm-up, weight training, aerobic endurance exercise, and a warm down component. Weight training involved single-arm curl (SAC)(10 repetitions), single-knee extension (SKE)(15 repetitions), and single-leg press (SLP)(15 repetitions) exercises. Initially, subjects completed two sets at 40 to 50% 1RM, but this progressed to three sets at 60 to 80% 1RM. The aerobic component involved 4 to 6 minutes of arm ergometry at approximately 70% of maximum heart rate, leg cycle ergometry at 60 to 85% of maximum H.R., and 10 minutes of walk\jogging at approximately 65 to 70% MAX METS. The Aer group exercise sessions were similar to the AerWt group except that weight training was replaced by recreational activities at approximately 30 to 40% of maximum METS.

Measurements of strength and functional capacity were recorded in all subjects pre- and post- training. The strength measures included the single maximum lift (1 RM) in the SAC, SKE, and SLP exercises, and isokinetic measurements in both the SKE at 90° and 180°/s, and the SLP at 30° and 75°/s. In addition, post-training, all subjects attempted to successively lift their pre-training 1RM weight as many times as possible. Two procedures were used to assess aerobic exercise function - a symptom limited maximum progressive incremental cycle ergometer test (Wmax), and a sub-maximal cycle ergometer test which measured the time to attain a Borg scale leg fatigue rating of 7 at 80% of initial Wmax. To assess changes in their ability to undertake a physically demanding task of daily living patients climbed 36 stairs at a normal rate of ascent and their subjective rating of perceived leg effort was recorded at the completion of the ascent using the Borg Scale. Prior to training the initial test(s) performance was similar between groups.

Maximum weightlifting strength (1RM) in single-arm curl, single-knee extension, and single-leg press exercises increased following training in the Aer group by 13% ($P < 0.01$), 5% (NS), and 4% (NS) respectively; corresponding gains in the AerWt group were 43% ($P < 0.01$), 24% ($P < 0.01$), and 21% ($P < 0.01$). Thus, the effectiveness of weightlifting training to increase voluntary dynamic strength in these CAD patients was demonstrated.

There was no significant increase in the isokinetic peak torque after training at any angular velocity in single-knee extension, and single-leg press exercise in the Aer (range of 1.6 to 2.5%) and AerWt (range 4.9 to 8.1%) groups. The unilateral isokinetic knee extension fatigue index was only slightly less in the Aer (6%, NS) and AerWt (7% ,NS) groups after training. These results support the concept of specificity of training.

Post-training, maximal incremental cycle ergometer performance (Wmax) increased by 2% (NS) in the Aer and by 15% ($P < 0.05$) in the AerWt group. The lack of Aer group improvement in aerobic performance (Wmax) with training may reflect several factors, particularly that having participated in an exercise rehabilitation programme for an average of 5.6 months prior to this study improvements in

Wmax may have already plateaued. Despite this the addition of weightlifting training in the experimental group effected a substantial, further improvement in Wmax.

Sub-maximal endurance measured as cycling time at 80% of initial Wmax before attaining a Borg RPE of 7 for the legs, increased by 11% (NS) and by 109% ($P < 0.05$) in the Aer and AerWt groups, respectively. These data suggest that the increased lower limb strength in the AerWt group served to reduce the perception of leg effort at a similar workload after training and thus facilitated exercise for a longer period of time before attaining a leg effort rating of 7.

In the stair climb the increase in exercise heart rate (average of 27 bpm) and Borg Scale leg RPE at the completion of the climb (average of 1.2) were slight in both groups, and were unaffected by training (NS). Thus, the minimal physical energy demands of this stair climbing task were demonstrated.

5.3 Recommendations

In the present study dynamic weightlifting training as an adjunct to aerobic endurance exercise training was a more effective method of increasing muscle strength and aerobic exercise capacity in these CAD patients than aerobic endurance training alone. Consequently, in order for similar community oriented cardiac exercise rehabilitation programmes to optimize exercise therapy, these programmes should consider the incorporation of a weightlifting component. Future research efforts may seek to determine to what extent CAD patients can safely tolerate a more intensive and long term weightlifting training regimen. The long-term effects of such a weightlifting\aerobic training programme on muscular strength and endurance, functional capacity, and the ability to perform activities of daily living may also be examined. Finally, radionuclide angiography could be used to assess the changes in rest and weightlifting exercise left ventricular function before and after a period of weightlifting training.

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6.0: APPENDICES

APPENDIX A: DIRECT MEASUREMENTS OF ARTERIAL BLOOD PRESSURE DURING FORMAL WEIGHTLIFTING IN CARDIAC PATIENTS

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Direct Measurements of Arterial Blood Pressure During Formal Weightlifting in Cardiac Patients

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J. Duncan MacDougall, PhD

Intra-arterial pressures and electrocardiographic responses were monitored in eight cardiac patients during progressive weightlifting exercise. Repetitions of single-arm curls, and double- and single-leg presses were performed at 20, 40, 60, and 80% of maximum. Within a weightlifting activity, the arterial pressures increased with relative load (% of maximum). At the three lowest relative loads, blood pressures over the same number of repetitions were similar among the three exercises; at 80% of maximum, single-arm curl exercise produced a prominent increase in the peak diastolic pressure. The highest heart rate and arterial pressures occurred during the double-leg press at 80% of maximum; the average mean arterial pressure and rate-pressure product at this load were 139 ± 7 mmHg and 249 ± 12 ($\times 10^2$), respectively. This rate-pressure product equaled the highest value in maximal progressive incremental cycle ergometer testing. Only double-leg exercise at 60%, and single- and double-leg exercise at 80% of maximum elicited a maximal rate-pressure product that exceeded the value calculated at 85% of the maximum power output in cycle ergometer testing. None of the weightlifting exercises resulted in clinically significant ST segment depression, angina, or significant ventricular arrhythmias. It was concluded that in this group of patients with documented coronary artery disease, weightlifting exercises that used relatively few repetitions and a resistance less than 80% of maximum resulted in clinically acceptable arterial blood pressure and electrocardiographic responses.

INTRODUCTION

Weightlifting exercise is a natural part of many daily activities. Strength training, as an adjunct to aerobic exercise, may thus be beneficial as a means of improving the functional capacity and quality of life of many patients with coronary artery disease who are deemed suitable for traditional cardiac exercise rehabilitation. Such exercises, however, are often associated with extreme elevations in arterial pressures among healthy young subjects.[1] Although the hemodynamic responses in patients with coronary artery disease during static[2-7] and dynamic[8-17] exercise have been examined extensively, the blood pressure and electrocardiographic responses of these patients to progressive weightlifting is uncertain. A recent study of circuit weight training in cardiac patients reported only small elevations in arterial pressures[18]; however, because measurements were made by auscultation after exercise, any sharp increases in pressures that may have occurred during the actual lifting maneuvers[1] would not have been detected by this indirect method. For strength training to be an accepted form of exercise in cardiac patients, the blood pressure and electrocardiographic changes should be no greater than those considered to be acceptable in dynamic exercise.[19]

The objective of this study was to assess the electrocardiographic and arterial blood pressure responses to single-arm, single-leg, and double-leg

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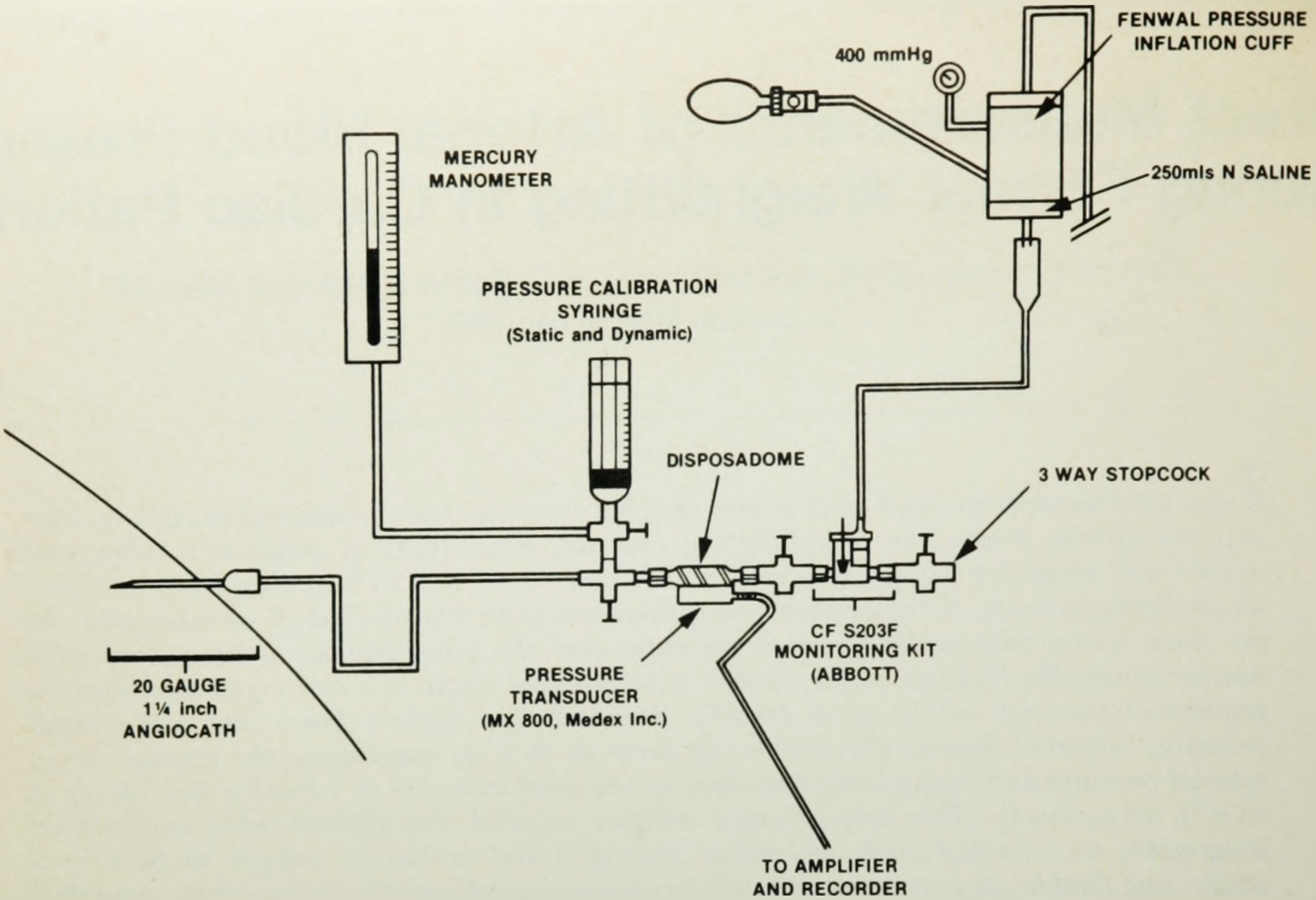


Figure 1. A schematic illustration of the blood pressure monitoring system used in this study (Modified from MacDougall JD, Tuxen D, Sale DG, Moroz JR, Sutton JR. Arterial blood pressure response to heavy resistance exercise. *J Appl Physiol* 1985;58:786.)

graded weightlifting exercises in patients with a documented previous myocardial infarction.

METHODS

Eight male patients, mean age 54 years (range, 46–65 years) with coronary artery disease and documented evidence of a previous myocardial infarction took part in the study. With one exception the myocardial infarctions had occurred within 12 months before the study, and two of the patients had undergone previous coronary artery bypass surgery. One patient had a myocardial infarction 12 years before the study but had been experiencing recurring symptoms of myocardial ischemia. Participation in the study was voluntary and all patients had been participating in the Chedoke-McMaster Hospitals Cardiac Exercise Programme for at least 1, and not more than 6, months. After a description of the procedures and associated risks, all subjects gave their written informed consent in accordance with the regulations issued by the institution's ethics committee.

The patients were screened to establish that there were no obvious contraindications to the proposed weightlifting activity. Exclusion criteria for the study included severe angina (> American Heart Association grade 2), exercise dysrhythmias (> Lown and Wolf grade 2), abnormal blood pressure response to exercise (a decrease in systolic pressure below resting; a decrease of greater than 20 mmHg in systolic pressure after the normal exercise increase; a rise in diastolic pressure of greater than 15 mmHg; a maximal systolic pressure in excess of 250 mmHg), respiratory limitation (documented restrictive or obstructive lung disease), ventricular aneurysm, maximal heart rate of less than 100 beats/min, and major orthopedic disability. Three patients were receiving nitrates, three were receiving calcium blockers, and two were receiving beta blockers; the patients continued to receive their usual medication throughout the study. A physician was in attendance throughout the studies, and the laboratory was equipped with appropriate resuscitation equipment.

The maximal aerobic exercise capacities of all patients were determined before this study using a progressive incremental cycle ergometer test.[19] In this test, two patients demonstrated ST-segment depression of 1–2 mm, one other subject experienced

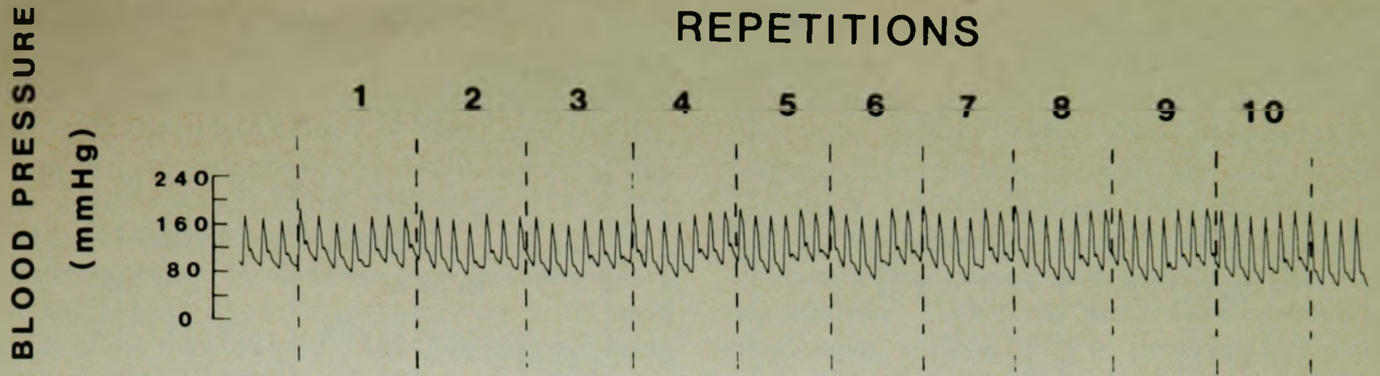


Figure 2. An actual trace of the blood pressure response in one subject performing a double-leg press exercise for 10 repetitions at 80% of his single maximum lift. Total elapsed time is approximately 40 seconds. It can be seen that the greatest increase in pressures occurs during the initial concentric phase and latter portion of the eccentric phase of each contraction.

moderate angina with no concurrent changes on the electrocardiogram. Measurements of the heart rate and systolic blood pressure were used to calculate the rate-pressure product (heart rate × systolic blood pressure × 10^{-2}) at 60, 85, and 100% of the patients' maximal exercise capacities.

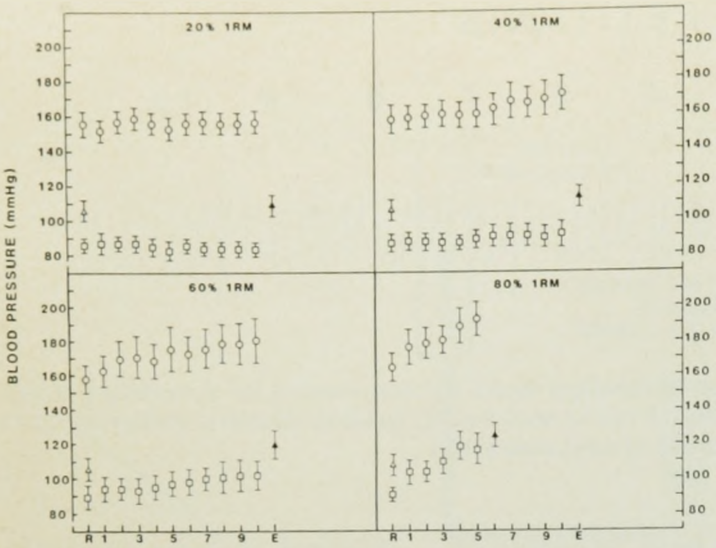
Measurement. After the injection with 2% xylocaine, a 20-gauge Angiocath (Deseret Medical Inc., Park-Davis and Co., Sandy, UT) was inserted percutaneously into the brachial artery, and blood pressure was recorded on line using a Novatrans transducer (MX 800, Medex Inc., Hilliard, OH), a custom designed amplifier and a Hewlett Packard (7402A) recorder (Fig. 1). Using a procedure similar to that used by MacDougall et al.,[1] the transducer was calibrated statically against a mercury manometer using a calibration syringe, and calibrated dynamically using square wave signals that were switched rapidly into the arterial line.[1] The baseline was checked, and the linearity of the transducer response was verified within the range of 0–360 mmHg, before and after the testing of each patient. Critical damping of the response was unnecessary as the calibration signal revealed that the resonant frequency of the measurement system would greatly exceed the frequency of a typical input signal; moreover, the distance between the catheter and the transducer was only a few inches. For each exercise the height of the pressure transducer was adjusted to midsternum level. Arterial blood pressure was recorded continuously before, during, and after the weightlifting activities, on a strip recorder at a usual paper speed of 5 mm/sec. The peak heart rate, peak systolic and diastolic blood pressure in each lift were derived from the blood pressure tracings. The maximum rate-pressure product was calculated as the product of the peak heart rate and the maximum systolic blood pressure in each exercise.[20] The mean arterial pressure in each exercise was derived on line from electronically calculated pressure integrals, each equivalent to 400 mmHg/sec.

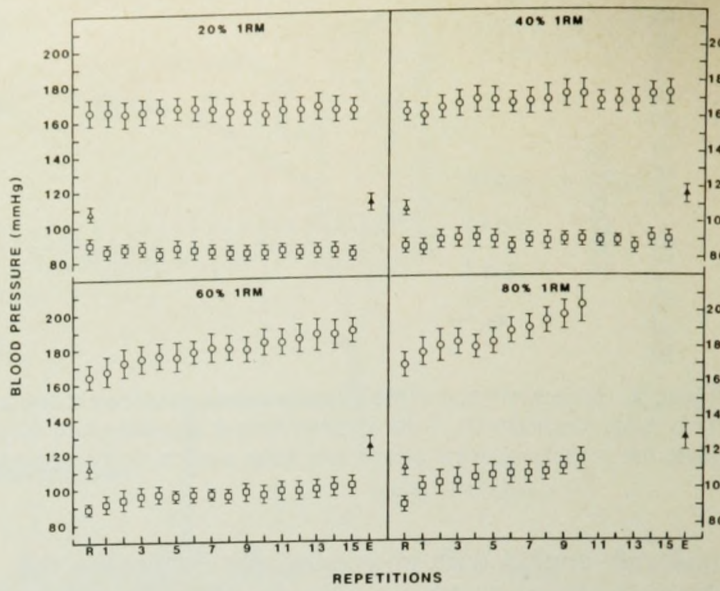
A 12-lead electrocardiogram (1515-B Automatic Cardiograph, Hewlett Packard) was recorded at rest, during the initial and intermediate repetitions of exercise, and immediately after the completion of each weightlifting exercise.

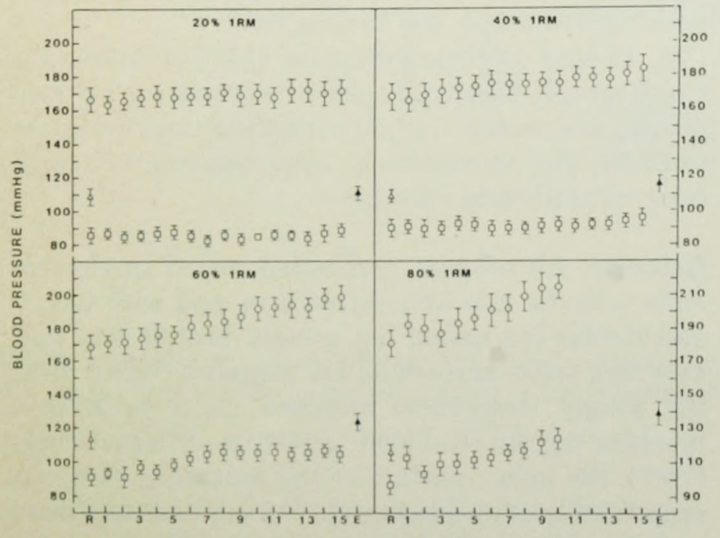
Exercise. All subjects performed seated single-arm curls with the noncatheterized arm, and both single- and double-leg seated leg presses. Seated arm curl exercises were performed on a pulley device with the weight (resistance) attached via a cable to a machine handle (Rubicon Industries, Stoney Creek, ONT); the upper portion of the exercising arm was supported by a curl pedestal. The leg exercises were performed on a Global Gym (4141-162) apparatus (Global Gym Inc., Downsview, ONT). Each subject's maximum single lift for each lifting activity (single-arm curl, single- and double-leg press) was determined during the week before the study session.

Single-arm curl exercise consisted of one set of 10 repetitions at 20, 40, and 60%, and one set of five repetitions at 80% of the patients' maximum single lift. Repetitions were performed at a moderate and comfortable pace. Both single- and double-leg press exercise consisted of 15 repetitions at 20, 40, and 60%, and 10 repetitions at 80% of the patients' maximum single lift. Subjects were instructed to breathe freely while exercising. Each set of exercise was followed by a recovery period of approximately 2 minutes.

Statistical Analysis. Statistical analysis of the effects of weightlifting activity, relative work load, and repetitions was accomplished by a two-way analysis of variance with repeated measures.[21] If, for a given variable, the analysis of variance indicated that a significant interaction existed between factors, the significance of specific differences was determined







Figures 3–5. Mean peak systolic, diastolic, and average arterial pressure responses to single-arm curl (top left), single-leg press (top right), and double-leg press (lower left) exercise at the relative loads as functions of the number of repetitions (abscissa) ○, mean peak systolic pressure, □, mean peak diastolic pressure, △, average mean arterial pressure at rest; ▲, average exercise mean arterial pressure. Data shown are mean ± SEM, N = 8

with a Newman Keuls multiple comparison test.[21] For all tests a difference was considered statistically significant at $P < .05$.

RESULTS

Relative Load. As occurs in healthy young subjects when lifting weights,[1] both systolic and diastolic pressures increased during each lift. In the current study, however, the pattern of change in pressures differed somewhat from that previously reported,[1] in that the greatest pressure change was recorded at the beginning of each concentric phase and the end of each eccentric phase with the magnitude of the increase being less during the intervening stages of each left (Fig. 2). This is in contrast to our previous finding of increased pressure during the lifting (concentric) phase and decreasing pressure during the lowering (eccentric) phase and may be attributed to the different exercise devices used in the two studies.

In the current study, lifting was performed on standard constant load devices so that the greatest point of effort occurred at the joint angle that corresponds to the weakest point on the strength curve. Thus for the arm curl and the leg press, effort was greatest as subjects began to lift the weight, became progressively less as the weight was elevated, and then increased again as the weight was lowered towards its starting position. In our previous study subjects performed leg presses on a variable resistance unit so that the actual force of contraction was caused to increase as the weight was lifted, causing the greatest effort to occur at the apex of the lift and then to decline as the weight was lowered to its starting position. In the current study the magnitude of the response varied according to the amount of weight lifted, so that the pressure increases were least when lifting at 20% of maximum and greatest when working at 80% of maximum.

Effect of Relative Load in a Given Weightlifting Activity. *Systolic Pressure.* In each weightlifting activity, the maximum mean peak systolic pressure was greater ($P < .001$) with an increasingly higher relative load (Figs. 3–5). The greatest mean peak systolic pressure for each weightlifting activity was recorded at the relative load of 80%, and for the one-arm curl, one-leg press, and double-leg press the values were (mean ± SEM) 193 ± 10, 204 ± 10, and 215 ± 7 mmHg, respectively.

Diastolic Pressure. In all three exercises, the maximum mean peak diastolic pressure rose with each increase in the relative load (Figs. 3–5); the increases between 40% and 60%, and 60% and 80%, were significant ($P = .001$) in all three weightlifting activities. Similar to the systolic pressure response, the greatest mean peak diastolic pressure values were recorded at the relative load of 80% of maximum, and were 119 ± 8 mmHg for the one-arm curl, 116 ± 6 mmHg for the one-leg press, and 124 ± 6 mmHg for the two-leg press.

Mean Arterial Pressure. In agreement with the changes in systolic and diastolic pressures, average mean arterial pressure also increased with increasing relative load (Figs. 3–5); the difference between rest and exercise was significant in all three exercises at the three highest relative loads ($P = .005$) (Figs. 3–5). For any given exercise, the grestest average mean arterial pressure occurred at the highest relative intensity, attaining a value 16, 15, and 20% greater than the resting value in the single-arm curl, single-leg press, and double-leg press, respectively.

Heart Rate and Rate-Pressure Product. In all three exercises, the heart rate and the rate-pressure product increased with increasing relative load (Table 1). The increase in the mean peak heart rate was significant between the relative intensities of 20% and 40% in all three exercises, and between 40% and 60% in both single- and double-leg lifting ($P = .008$), but increased only slightly between the relative loads of 60% and 80%. In all three weightlifting activities the mean maximum rate-pressure product increased significantly ($P = .002$) with each increase in the relative load (Fig. 6, Table 1).

Effect of Repetitions. The absolute and relative increase in the mean peak systolic pressure from rest to the final repetition of each set was significant ($P = .02$) at 40, 60, and 80% of maximum in all exercises (Figs. 3–5). There was a significant rise in the mean peak diastolic pressure from rest to the completion of lifting in all three exercises at 60 and 80% of maximum ($P = .001$) (Figs. 3–5), but the relative change was only significant in all three exercises at a relative intensity of 80% of maximum ($P = .003$).

Effect of Different Weightlifting Activities at a Given Relative Load. *Systolic Pressure.* At the three lowest relative loads the maximum mean peak systolic blood pressure response in all three exercises was only slightly higher (NS) with increasingly larger active muscle mass, when the total number of repetitions was standardized. Over the course of the initial five repetitions at 80% of maximum, the greatest systolic pressure was recorded in the double-leg exercise. Under the same exercise conditions, single-arm curling, which involved the smallest active muscle mass, elicited a maximum mean peak systolic pressure that was greater than the corresponding pressure recorded during five repetitions of single-leg exercise. The maximum mean peak systolic pressure was greater in the double-leg press than in the single-leg press over 15 repetitions at the relative loads of 40% (184 ± 8 mmHg vs. 174 ± 7 mmHg, $P = .058$) and 60% (199 ± 7 mmHg vs. 190 ± 7 mmHg, $P = .046$); differences at the relative intensities of 20 and 80% of maximum were not significant.

Diastolic Pressure. The diastolic pressure values for each activity were similar during lifting at the three lowest intensities. Only at 80% of maximum was there a substantial difference in the mean peak diastolic blood pressure response, when the maximum mean value was greater during single-arm exercise (119 ± 8 mmHg) than during single-leg (107 ± 7 mmHg) ($P = .02$) and double-leg (113 ± 7 mmHg) exercise over the initial five repetitions. However, the value during double-leg exercise was greater over the course of 10 repetitions (124 ± 6 mmHg) than the corresponding value in single-leg press exercise (116 ± 6 mmHg) and higher than the level recorded during single-arm exercise over five repetitions (119 ± 8 mmHg).

Mean Arterial Pressure. At any given relative work load the average exercise mean arterial pressures among weightlifting activities were similar. At 80% of maximum the average mean arterial pressures increased, although not significantly, in ascending order of active muscle mass.

Heart Rate. There was no consistent effect of weightlifting activity on mean peak heart rate until the relative intensities of 60 and 80% of maximum, when the mean peak value was higher ($P = .008$) with increasingly greater active muscle mass (Table 1).

Rate-Pressure Product. In double-leg exercise the mean maximum rate-pressure product was greater ($P = .002$) than in both single limb exercises at the three highest relative loads (Table 1). Compared with single-arm work, the value in single-leg work was greater at 60 and 80% of maximum ($P = .002$) (Table 1). At 80% of maximum, 10 repetitions of

TABLE I
MEAN PEAK HEART RATE AND MEAN MAXIMUM RATE-PRESSURE PRODUCT RESPONSES TO SINGLE-ARM CURL, SINGLE- AND DOUBLE-LEG PRESS WEIGHTLIFTING

	Relative Load							
	20%		40%		60%		80%	
	HR	RPP	HR	RPP	HR	RPP	HR	RPP
Weightlifting activity								
1-arm curl	90 ± 5	144 ± 12	97 ± 6	167 ± 15	100 ± 6	182 ± 18	104 ± 6	202 ± 16
1-leg press	85 ± 4	146 ± 9	95 ± 4	167 ± 10	106 ± 4	202 ± 13	110 ± 5	228 ± 14
2-leg press	90 ± 4	157 ± 10	100 ± 5	186 ± 14	114 ± 7	227 ± 15	116 ± 6	249 ± 12

HR = mean peak heart rate (beats/min). RPP = mean maximum rate-pressure product (mean peak heart rate X mean maximum systolic pressure X 10^{-2}.

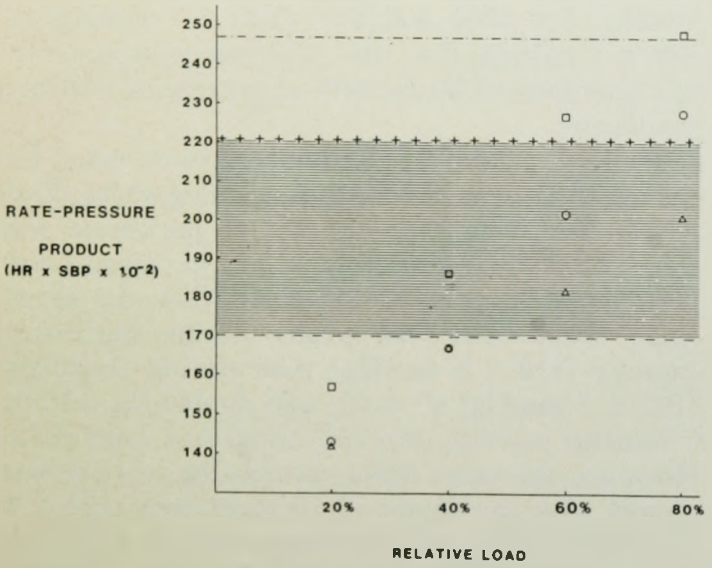


Figure 6. Mean maximum rate-pressure product (mean maximum peak heart rate X mean maximum peak systolic pressure X 10^{-2}) responses to single-arm curl, single- and double-leg press exercise as functions of relative work intensity (plotted as % of single maximum lift); △, single-arm curl; ○, single-leg press, □, double-leg press. The mean rate-pressure product values recorded in progressive incremental cycle ergometer testing at 60%, 85%, and 100% of the maximum achieved work are also indicated ----, 60%, ++++, 85%; - - -, 100%. Data are shown as mean ± SEM, N = 8.

double-leg exercise elicited a mean maximum rate-pressure product (249 ± 12) that was similar to the value (247 ± 11) obtained during maximal progressive incremental cycle ergometer testing (Fig. 6).

Ischemia. Weightlifting did not precipitate any adverse electrocardiographic changes or symptoms of angina in any of the patients, although three of them had previously demonstrated myocardial ischemia during maximal cycle ergometer testing.

DISCUSSION

Because normal daily functioning may require an individual to climb stairs and to lift and carry heavy objects, an increase in overall body strength provides a greater reserve that may improve the quality of daily life. Therefore, strength training in cardiac patients as part of exercise rehabilitation may be a useful addition to traditional large muscle group aerobic exercise. Several studies have examined the relative safety of weight carrying and lifting in selected patients with a previous myocardial infarction.[11,14,18,22] More research was necessary to determine the safe limits for weightlifting activities using moderate to heavy resistance. This study attempted to determine whether cardiac patients without precluding contraindications could safely lift moderate to heavy weights in a rhythmic fashion, as commonly used in weight training regimens.

It is recognized that the validity of the brachial artery blood pressure recordings in the current study could be challenged, had contractions occurred in the catheterized arm or in the presence of brachial artery spasms.[1] The possibility of brachial artery compression due to contraction of the nonexercising forearm flexors was minimized by preventing the subjects from grasping any portion of the exercise apparatus with the arm, and by coaching throughout the procedures. Moreover, analysis of the clarity and distinctiveness of the recorded tracings (Fig. 2) supports the validity of the brachial artery blood pressure measurements.

During weightlifting at 40% of maximum the highest mean peak systolic pressures recorded in this study (average of mean ± SEM, 176 ± 8 mmHg in all 3 exercises) were substantially higher than the value (141 ± 20 SD) reported by Kelemen et al.[18] in coronary heart disease patients during circuit weight training at the same relative intensity (40%) for a similar duration (10–15 repetitions). The systolic pressures recorded at rest in the current study exceeded the peak systolic pressure response to circuit weight training reported by Kelemen et al.[18] This group, however, measured the blood pressure indirectly with a cuff immediately after the actual lifting. Such a strategy would not allow the measurement of the elevated arterial pressure that occurs during exercise, and which is followed by a rapid decline in pressure after the final lift.[1] The direct measurement of arterial pressure in the current study obviated this problem.

Effect of Relative Load in a Given Weightlifting Activity. In all three weightlifting exercises the systolic pressures increased with each increment in the relative load. Despite the increased afterload, however, the relatively constant average pulse pressure suggests that the stroke volume was maintained, and ventricular function was not compromised. This is in agreement with the recent conclusions of Butler et al.,[23] who assessed left ventricular function in cardiac patients after weightlifting exercise using echocardiography.

Assuming that the rate-pressure product during lifting in the current study was a reflection of the myocardial oxygen demand, certain weightlifting exercises appear entirely suitable for cardiac patients involved in traditional exercise rehabilitation. The normal recommendation for exercise prescription is to attain a working level betwen 50% and 85% of the maximal functional capacity achieved in graded exercise testing.[24] Given these guidelines it appears that weightlifting in cardiac patients is safe at a level below 60% of the one repetition maximum (Fig. 6). On the other hand, it may be inadvisable for cardiac patients to engage in weightlifting at a high relative load. In the current study, single-leg lifting at 80%, and double-leg lifting at 60% and 80% of maximum, produced a rate-pressure product that exceeded the value attained during cycle ergometer testing at 85% of maximum power (Fig. 6); single-arm exercise at 80% resulted in a higher double product after only five repetitions (Fig 6). Although the double product during weightlifting at high relative intensities attained higher levels than in cycle ergometer testing at 85% of maximal power, the results must be interpreted with caution. During weightlifting, the elevated myocardial oxygen demand is maintained for approximately 30 seconds, whereas in the cycling test the demand is sustained for several minutes. Taking this into consideration, it seems reasonable to propose that under the conditions of this study the risk of developing ischemia, and compromised left ventricular function, was probably less during weightlifting than during a conventional clinical exercise test.

Effect of Weightlifting Activities at a Given Relative Load. There was no consistently marked effect of muscle mass on the arterial pressures at any given relative load, suggesting that a balance existed between the total systemic conductance and the cardiac output.[25,26] Lewis and associates[25,26] have shown that small-muscle dynamic and isometric exercises produce a modest increase in the systemic oxygen demand and the cardiac output; under these exercise conditions systemic vascular resistance remains near resting levels because local vasodilation has only a minor effect on the total systemic conductance.[25,26] Therefore, any increase in the heart rate and cardiac output is associated with a marked increase in the mean arterial pressure.[25] On the other hand, in large muscle group dynamic exercises, metabolic vasodilation greatly increases the total systemic conductance.[25,26] This vascular response permits a relatively slight increase in the mean arterial pressure despite a much greater increase in the heart rate, cardiac output, and systemic adrenergic vasoconstrictor drive.[25]

At the two highest relative work loads, the maximum mean peak heart rate was greater with increasing muscle mass. This finding is consistent with the work of several authors[25–27] who reported that in dynamic exercise at a given relative load, the heart rate increases with the increase in oxygen uptake and therefore rises to a greater degree in large muscle work.

At each load in all three exercises, the pulse pressure response was greater with increasing active muscle mass. This was perhaps attributable to an enhanced venous return and an augmentation of stroke volume by the Frank–Starling mechanism. The increased pulse pressure in the absence of untoward symptoms and no electrocardiographic evidence of ischemia support the contention that the ventricular function of the patients was not compromised during this exercise, which is in agreement with the recent findings of Butler and colleagues.[23] Furthermore, the weightlifting exercise in this study did not induce any significant arrhythmias. This finding is consistent with the results of other researchers who noted infrequent cardiac arrhythmias during isometric exercise,[2,12] weight carrying,[11] and circuit weight training.[18]

In summary, the average exercise mean arterial pressure and maximal rate-pressure product increased with increasing relative load in all three weightlifting activities. At the relative loads of 20%

and 40% of maximum, the arterial pressure adjustment to exercise was modest, but there were more prominent increases in the arterial pressures at 60% and 80% of maximum. Under the conditions of this study, the arterial blood pressure and electrocardiographic responses of cardiac patients during single-arm and single-leg weightlifting at loads less than 80% of maximum, and double-leg lifting at less than 60% of maximum, were judged to be within acceptable limits. The highest rate-pressure product in the current study was elicited by double-leg lifting at 80% of maximum, but this value was no greater than the corresponding value calculated during clinical exercise testing on a cycle ergometer.

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APPENDIX B: INFORMED CONSENT

TRAINING STUDY 1987

CONSENT FORM

The purpose of this study is to investigate the effects of weight training on muscle strength, endurance, and performance in a selected activity of daily living. Participation in this study requires attendance at 90 minute exercise sessions, 2 times a week for a total of 10 weeks.

A series of 5 tests will be performed before and after the 10 week (20 session) training programme. These are:

1. A graded exercise test measuring heart and lung function.
2. A submaximal cycling test to measure endurance capacity.
3. A stair climbing test.
4. Measures of maximal muscle strength in three weightlifting exercises.
5. A test to measure maximal muscle power in single limb contractions at constant speed.

1. Graded cycle ergometer test: This will be done on a cycle ergometer. The work will begin at a very easy level and will gradually become more difficult. We would like you to continue to exercise until you are limited by fatigue or extreme discomfort. We will be closely monitoring your test; if we see any reason to stop the test prematurely, we will do so at once. While exercising, you will breathe through a mouthpiece to measure how much oxygen you use. We will ask you to use a noseclip to make sure that all the air is inhaled and exhaled through the mouth. An electrocardiogram will monitor your heart rate and rhythm. A cuuf around your arm will be inflated every 2 minutes to measure your blood pressure. This test will take approximately one hour.

Exercise Training:

Participants in this study will be randomly assigned to either a weight training or a non-weight training group. Each training session in the weight training group will involve (i) warm up; (ii) weight lifting exercises- 1 to 3 sets of a single-arm exercise (10 repetitions) and four single-leg exercises (15 repetitions), using submaximal weight; (iii) cardiorespiratory endurance activities and; (iv) warm down. The non-weight training group will engage in recreational activities instead of the weight lifting exercise.

There exists the possibliity of similar adverse changes occuring during the exercise training sessions. Emergency equipment is available at all times in the exercise laboratory and a physician will always be pleased to discuss them with you.

Participation in this study is voluntary. You may withdraw your consent at any tiem, even after signing this form. Any information that is collected about you during this study will be kept confidential, and if the results are published, you will not be identified in any way.

If you agree to participate, please accept our thanks and indicate your consent by signing below.

Subject Signature	Witness Signature
Subject Name (please print)	Witness Name (please print)
	Date

. . . .

I have explained the nature of the study to the subject and believe that he has understood it.

Name	Signature	Date

APPENDIX C: WEIGHT TRAINING REGIMEN AND PROGRESSION

(i) Weightlifting training intensity (% 1RM) for single-arm curl exercise over the course of the study

Session	Set 1	Set 2	Set 3
1	40	49	
2	42	53	
3	50	53	
4	51	53	
5	59	59	
6	62	62	
7	63	63	64
8	63	63	67
9	64	65	70
10	64	65	65
11	66	68	70
12	68	69	71
13	71	72	73
14	70	71	70
15	72	73	72
16	71	73	76
17	73	74	74
18	73	74	74
19	75	75	75
20	75	76	76

(ii) Weightlifting training intensity (% 1RM) for single-knee extension exercise over the course of the study

Session	Set 1	Set 2	Set 3
1	40	47	
2	40	49	
3	48	50	
4	49	51	
5	55	55	
6	56	57	
7	58	58	59
8	59	59	60
9	57	59	60
10	58	58	59
11	58	59	60
12	59	60	61
13	61	62	62
14	62	63	64
15	62	64	63
16	64	64	65
17	63	64	64
18	64	65	65
19	67	67	67
20	67	68	68

(iii) Weightlifting training intensity (% 1RM) for single-leg press exercise over the course of the study

Session	Set 1	Set 2	Set 3
1	40	47	
2	41	49	
3	47	49	
4	48	51	
5	55	55	
6	56	57	
7	60	60	61
8	60	61	62
9	61	61	61
10	61	61	62
11	62	62	64
12	64	65	66
13	66	66	67
14	67	68	69
15	68	69	69
16	71	71	71
17	71	72	72
18	73	73	73
19	73	73	73
20	73	73	74

APPENDIX D: MUSCLE STRENGTH, AEROBIC EXERCISE CAPACITY, AND STAIR CLIMBING TESTING SCHEDULE

TEST DAY	**1 (a)**	**1 (b)**	**2 (a)**	**2 (b)**
STAFF	5	5	5	5
TESTING	(i) 1RM	1 RM	Repeat 1RM	Repeat 1RM
	12 subjects	13 subjects	12 subjects	13 subjects
	(ii) Stair Climb	Stair Climb	Repeat Stair Climb	Repeat Stair Climb
	12 subjects	13 subjects	12 subjects	13 subjects
	(iii) Symp. Limit. Max. on Tues., Thurs. grp.	(iii) Symp. Limit. Max. on Mon., Wed. grp.	(iii) Symp Limit. Max on Tues., Thurs grp.	(iii) Symp. Limit. Max. on Mon., Wed. grp.
	4 subjects	3 subjects	3 subjects	3 subjects
TEST DAY	3 (a)	3 (b)	4 (a)	4 (b)
STAFF	2	2	2	2
TESTING	(i) Single Max. Vol. Isokin. Contraction	Single Max. Vol. Isokin. Contraction	Isokin. Fatigue	Isokin. Fatigue
	12 subjects	13 subjects	12 subjects	13 subjects
	(ii) Symp. Limit. Max. on Tues., Thurs. grp.	Symp. Limit. Max. on Mon., Wed. grp.	Symp. Limit. Max on Tues., Thurs. grp	Symp. Limit. Max. on Mon., Wed. grp.
	3 subjects	3 subjects	3 subjects	3 subjects

(cont.)

(Appendix D cont.)

TEST DAY	5 (a)	5 (b)
STAFF	2	2
TESTING	(i) Submax. End. 12 subjects	(i) Submax. End. 13 subjects

Post- training all subjects performed the absolute weightlifting endurance test on a day when they did not undergo any other measurements

APPENDIX E: RAW DATA SCORES

(i) a) The maximum weight lifted (1RM) in single-arm curl exercise

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	kg	kg	kg	kg
001	12.5	13.5	11.5	12.8
002	14.8	16	12.8	14
003	12.5	13.3	10.5	11.8
004	8.5	11.5	10	12
005	10.5	11.8	10.3	12
006	10	11	8.5	9.5
007	16	16.5	12.5	13.5
008	14.5	19	14	15
$\bar{x}$	12.4	14.1	11.3	12.6
± S.E.M.	0.9	0.9	0.6	0.6
AerWt group	kg	kg	kg	kg
009	13.3	16.5	10.5	14
010	14.8	21.8	12.3	20.5
011	14.3	20.3	11.3	16.3
012	14	21	11.5	15.5
013	16	22	14	21
014	16.5	22	15.8	20
015	8	14	8.75	14
016	14	19.5	10	14.8
017	9	11.8	7.5	10
018	11.8	16.5	11.8	15.7
$\bar{x}$	13.2	18.5	11.3	16.2
± S.E.M.	0.8	1.1	0.7	1.0

(i) b) The maximum weight lifted (1RM) in single-knee extension exercise

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	kg	kg	kg	kg
001	26.3	29	26.3	29
002	26	26.3	24	28.8
003	27	27.8	35	35
004	17.5	18.8	17.5	18.8
005	32.5	injury	32.5	33.5
006	23.8	24.3	22.5	23
007	36.3	38.5	35	36.3
008	37.5	40	40	40
$\bar{x}$	27.8	29.2	29.1	30.5
± S.E.M.	2.5	2.7	2.5	2.4
AerWt group	kg	kg	kg	kg
009	21.3	27.5	20	26
010	32.5	41	36	42.5
011	38.8	46.3	36.3	45
012	32.5	40	30	40
013	47	53	47	53
014	26.3	41	32.5	42.5
015	22.5	26	22.5	26.8
016	27.5	33.8	30	37.5
017	15.5	20.3	15	19.5
018	22.5	29	22.5	29.3
$\bar{x}$	28.6	35.8	29.2	36.2
± S.E.M.	2.8	3.1	2.8	3.1

(i) c) The maximum weight lifted (1RM) in single-leg press exercise

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	kg	kg	kg	kg
001	82.5	86	82.5	87.5
002	100	100	102	106.3
003	97.5	105	98.8	103.8
004	85	88.8	72.5	82.5
005	86.3	injury	78.8	85
006	87.5	93	95	100
007	145	147	130	133
008	86.3	90.5	88.8	92.5
$\bar{x}$	97.7	101.5	93.6	98.8
± S.E.M.	7.7	7.4	5.9	5.4
AerWt group	kg	kg	kg	kg
009	95	115	90	108
010	95	122	95	115
011	130	148	100	118.5
012	107.5	154	115	155
013	115	137	107.3	124
014	96.3	115	98.8	119
015	85	98	86.3	98
016	100	118	100	118
017	80	93.8	74	87.5
018	108.8	130	101.3	120
$\bar{x}$	101.3	123.1	96.8	116.3
± S.E.M.	4.4	5.9	3.4	5.3

(ii) a) The number of times post- training that the pre-training 1RM (once only) could be lifted successively in the single-arm curl exercise

Subject	Right arm	Left arm
Aer group		
001	6	8
002	2	2
003	1	4
004	12	5
005	2	2
006	5	3
007	1	2
008	10	3
$\bar{x}$	4.9	3.6
± S.E.M.	1.4	0.7
AerWt group		
009	13	14
010	13	15
011	13	16
012	15	16
013	10	11
014	14	13
015	23	22
016	12	12
017	14	16
018	10	13
$\bar{x}$	13.7	14.8
± S.E.M.	1.1	0.9

(ii) b) <u>The number of times post- training that the pre-training 1RM (once only) could be lifted successively in the single-knee extension exercise</u>

Subject	Right knee	Left knee
Aer group		
001	2	2
002	2	5
003	1	1
004	4	5
005	injury	1
006	1	1
007	3	1
008	2	3
$\bar{x}$	2.1	2.4
± S.E.M.	0.4	0.6
AerWt group		
009	7	8
010	7	5
011	7	5
012	6	10
013	2	3
014	17	15
015	7	6
016	6	5
017	17	16
018	13	12
$\bar{x}$	8.9	8.5
± S.E.M.	1.5	1.4

(ii) c) The number of times post- training that the pre-training 1RM (once only) could be lifted successively in single-leg press exercise

Subjects	Right leg	Left leg
Aer group		
001	3	4
002	1	3
003	3	3
004	6	7
005	injury	2
006	7	7
007	1	1
008	7	7
$\bar{x}$	4	4.3
± S.E.M.	0.9	0.8
AerWt group		
009	25	25
010	33	32
011	10	11
012	31	16
013	13	17
014	26	27
015	12	8
016	19	16
017	22	19
018	23	20
$\bar{x}$	21.4	19.1
± S.E.M.	2.4	2.2

(iii) a) The peak torque (N.m) generated in isokinetic single-extension exercise at an angular velocity of 90°/s

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	N.m	N.m	N.m	N.m
001	148	168	143.8	152.5
002	187.5	175	165	154
003	148	147	182	174
004	103	112.5	104	122.5
005	172	injury	162.5	180
006	144	134	135	134
007	217.5	229	182.5	182.5
008	192.5	213	200	200
$\bar{x}$	162.9	168.4	159.4	162.4
± SEE	13.4	14.6	10.9	8.7
AerWt group	N.m	N.m	N.m	N.m
009	138.5	152.5	122	125
010	190	211.5	172	200
011	208	247	197	217.5
012	212.5	237	176.5	207.5
013	203	195	212	207
014	175	182	194	185.5
015	142.5	145	122.5	146
016	180	191.5	172	180
017	142.5	155	112	117.5
018	162	176	142.5	161
$\bar{x}$	175.4	189.3	162.3	174.7
± SEE	8.5	10.4	10.6	10.7

(iii) b) The peak torque (N.m) generated in isokinetic single-knee extension exercise at an angular velocity of 180°/s

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	N.m	N.m	N.m	N.m
001	118	132	119	122.5
002	149	130	137.5	125
003	117	122	152	142.5
004	104	97.5	113.5	107
005	131	injury	130	142.5
006	113.5	112.5	106	105
007	170	209	154	167
008	181.5	184	170	180
$\bar{x}$	136.1	141	135.3	136.4
± S.E.M.	10.7	14.1	7.4	8.9
AerWt group	N.m	N.m	N.m	N.m
009	134	147.5	100	102.5
010	165	207	131.5	165
011	167.5	190	159	172
012	190	222.5	145	145
013	187	192	176	175
014	164	158.5	170	172.5
015	122	125	110	114
016	167.5	175	129	144
017	109	115	100	100
018	125	141	115	135
$\bar{x}$	153.1	167.4	133.6	142.5
± S.E.M.	8.5	10.7	8.4	8.7

(iii) c) The average torque (N.m) generated in isokinetic single-knee extension exercise at an angular velocity of 90°/s

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	N.m	N.m	N.m	N.m
001	91.5	118.7	86.5	110.1
002	109.9	76.2	97.6	78.1
003	90.9	88.8	113.4	102.3
004	64.8	66.1	62.5	70.4
005	100.1	injury	89.2	100.9
006	84.9	79.2	77.6	84.2
007	135.9	138	111.9	135
008	120.5	106	129.8	104.2
$\bar{x}$	99.8	96.1	96.1	98.2
± S.E.M.	8.4	9	7.2	6.8
AerWt group	N.m	N.m	N.m	N.m
009	73.9	69.8	80.2	66.4
010	97.8	97.4	94.8	98.2
011	108.9	154.9	120.4	132.9
012	120.2	125.8	104	107.9
013	115.2	115.1	130.4	126.6
014	93.4	91.3	114.9	97.4
015	82.9	82.1	76.5	91.4
016	109	140.2	104.6	161.5
017	81.4	80.9	59	71.7
018	84.6	96.1	83	92.4
$\bar{x}$	96.7	105.4	96.8	104.6
± S.E.M.	4.8	8.3	6.7	8.7

(iii) d) The average torque (N.m) generated in isokinetic single-knee extension exercise at an angular velocity of 180/s

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	N.m	N.m	N.m	N.m
001	67.2	90.6	58.5	84.1
002	76.1	69.1	78.4	59.7
003	73.4	76.3	76	77.8
004	43.5	45.7	47.2	51.6
005	68.1	injury	69.3	68.8
006	60.3	57.1	60.5	57.5
007	88.4	90.2	78.5	77.2
008	93.3	78.4	89.8	78.4
$\bar{x}$	71.7	72.5	69.8	69.4
± S.E.M.	5.9	5.8	4.5	3.9
AerWt group	N.m	N.m	N.m	N.m
009	64.9	64.6	64	51.3
010	80.4	87.7	76.8	79.4
011	95.1	96	82.2	102
012	97.6	93.8	79.9	81.4
013	89.7	99.1	96.3	85.9
014	82.5	84.9	88.5	87.5
015	60	59	58	56.3
016	83	138	71.6	83.3
017	57.4	54.3	39.1	50.4
018	64.6	74.2	59.8	71.4
$\bar{x}$	77.5	85.2	71.6	74.9
± S.E.M.	4.4	7.3	5	5.2

(iii) e) The impulse (N.m.s) generated in isokinetic single-knee extension exercise at an angular velocity of 90°/s

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	N.m.s	N.m.s	N.m.s	N.m.s
001	80.5	103.5	74	92.5
002	87	53	89	50
003	90.5	76	97.3	88
004	62.8	59	50	58
005	92.5	injury	83.5	92
006	78	76	54	66
007	144	147	110	145
008	107.5	82	108	77.5
$\bar{x}$	92.9	85.2	83.2	83.6
± S.E.M.	9.2	11.1	7.51	9.7
AerWt group	N.m.s	N.m.s	N.m.s	N.m.s
009	73	72	77	59
010	91.5	88	91	86
011	122	132	103.5	110
012	111	80	84	82
013	111.5	105	120	118
014	74	84	103	74
015	63	75.5	68.5	79
016	95.5	87.5	89.5	84
017	75.5	87	53.3	70
018	80.5	98	77	92
$\bar{x}$	89.8	90.9	86.7	85.4
± S.E.M.	5.9	5.2	5.8	5.3

(iii) f) The impulse (N.m.s) generated in isokinetic single-knee extension exercise at an angular velocity of 180°/s

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	N.m.s	N.m.s	N.m.s	N.m.s
001	32.5	39.5	22	34
002	28	22	32	21
003	35.5	29	36.5	33
004	19.5	19	17	19
005	30.5	injury	33	30
006	28	31.5	23	23
007	43.5	44	38	38
008	43.3	37	39.5	32
$\bar{x}$	32.9	31.7	30.1	28.8
± S.E.M.	3.1	3.2	2.8	2.3
AerWt group	N.m.s	N.m.s	N.m.s	N.m.s
009	30.5	30.5	31.5	19.5
010	36	36.5	35	34
011	54	53	35.5	40
012	41	30	31	28
013	42	42	42	46
014	32	36	40	35
015	26	25	25.5	27
016	36.5	31	29.5	25
017	25.5	28	18	23
018	30.5	38	26.3	34
$\bar{x}$	35.4	35	31.4	31.2
± S.E.M.	2.6	2.4	2.2	2.4

(iii) g) The peak torque (N.m) generated in isokinetic single-leg press exercise at an angular velocity of 30°/s

Subject	Right pre-	Right post-	Left pre-	Left post-
Aer group	N.m	N.m	N.m	N.m
001	520	474	510	506
002	432	490	426	528
003	404	420	504	520
004	256	290	270	310
005	480	injury	440	450
006	432	428	468	460
007	706	640	588	650
008	560	504	570	570
$\bar{x}$	472.9	463.7	472.0	499.3
± S.E.M.	53.3	39.9	35.2	35.1
AerWt group	N.m	N.m	N.m	N.m
009	496	490	446	492
010	536	668	496	628
011	708	736	638	624
012	670	690	690	774
013	672	630	630	620
014	640	620	660	680
015	420	490	436	430
016	512	500	514	532
017	448	474	392	400
018	580	580	529.2	596
$\bar{x}$	568.2	587.8	543.1	577.6
± S.E.M.	31.9	30.1	33.1	36.3

(iii) h) The peak torque (N.m) generated in isokinetic single-leg press exercise at an angular velocity of 75°/s

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	N.m	N.m	N.m	N.m
001	430	400	420	410
002	428	408	410	430
003	360	370	420	440
004	180	180	190	240
005	416	injury	380	410
006	340	376	340	360
007	576	604	560	576
008	440	448	480	472
$\bar{x}$	393.4	398.0	400.0	417.3
± S.E.M.	45.7	47.3	38.0	33.7
AerWt group	N.m	N.m	N.m	N.m
009	390	430	352	410
010	440	552	470	526
011	596	566	500	484
012	588	610	570	604
013	532	496	488	480
014	480	530	544	544
015	320	340	300	340
016	428	420	412	430
017	388	396	290	330
018	408	440	370	448
$\bar{x}$	457.0	478.0	429.6	459.6
± S.E.M.	28.7	27.2	31.4	27.5

(iii) i) The average torque (N.m) generated in isokinetic single-leg press exercise at an angular velocity of 30°/s

Subjects	Pre- Right	Post- Right	Pre- Left	Post- Left
Aer group	N.m	N.m	N.m	N.m
001	289.6	270.8	327.6	321.2
002	301.2	244.8	307.6	270.8
003	278.4	287.6	325.6	334.8
004	181.6	179.6	192.8	191.2
005	267.6	injury	288.8	136
006	270	261.2	281.6	278
007	432	363.6	335.6	377.6
008	388	327.6	374.4	359.6
$\bar{x}$	305.8	276.5	304.3	283.7
± S.E.M	31.0	22.4	18.9	29.6
AerWt group	N.m	N.m	N.m	N.m
009	298	280.4	258	291.6
010	319.6	340.8	303.2	370.8
011	418	406.8	378.4	350
012	399.2	403.2	390.8	428.4
013	388	363.6	341.2	355.2
014	328.4	342.8	384	396.8
015	242.8	267.6	264.4	282
016	316.4	324.4	304	309.2
017	257.6	276	241.2	237.6
018	364	309.6	326.4	369.2
$\bar{x}$	333.2	331.5	319.2	339.1
± S.E.M.	18.6	15.8	17.2	18.4

(iii) j) The average torque (N.m) generated in isokinetic single-leg press exercise at an angular velocity of 75°/s

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	N.m	N.m	N.m	N.m
001	260.4	251.6	280.8	267.6
002	299.6	214.4	288	253.6
003	259.2	232.8	284.4	265.6
004	105.6	125.2	118	153.2
005	246.8	injury	238	264.4
006	223.6	234.4	227.6	226.4
007	349.6	347.2	343.6	345.2
008	286.8	288.8	314	296.8
$\bar{x}$	254.9	242.1	261.8	259.1
± S.E.M.	28.9	25.8	24.4	19.5
AerWt group	N.m	N.m	N.m	N.m
009	225.2	270	224.4	261.2
010	260	303.2	270.8	287.6
011	342	333.2	317.6	286.4
012	347.2	376.8	335.6	335.6
013	322.8	302.4	296	308.8
014	269.2	307.6	292.4	313.6
015	198.4	209.6	189.6	219.2
016	270.4	293.2	250	297.6
017	226.8	240.4	184.4	208
018	245.2	288.8	248	268.4
$\bar{x}$	270.7	292.5	260.9	278.6
± S.E.M.	16.2	14.7	16.2	12.8

(iii) k) The impulse (N.m.s) generated in isokinetic single-leg press exercise at an angular velocity of 30°/s

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	N.m.s	N.m.s	N.m.s	N.m.s
001	424	428	438	488
002	648	292	700	404
003	450	458	573.2	580.8
004	212	280	212	280
005	412	injury	388	180
006	416	404	408	396
007	648	512	576	556
008	546	540	584	624
$\bar{x}$	477.7	416.3	484.9	438.6
± S.E.M.	57.9	37.9	54.1	54.4
AerWt group	N.m.s	N.m.s	N.m.s	N.m.s
009	354	480	322	456
010	540	536	524	590
011	734	620	646	528
012	484	516	453.2	538
013	636	544	643.2	614
014	398	428	430	476
015	308	348	310	468
016	362	480	446	516
017	338	382	381.2	340
018	460	488	432	524
$\bar{x}$	461.4	482.2	458.8	505.0
± S.E.M.	44.2	25.4	36.8	24.3

(iii) 1) The impulse (N.m.s) generated in isokinetic single-leg press exercise at an angular velocity of 75°/s

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	N.m.s	N.m.s	N.m.s	N.m.s.
001	148	170	165.2	184
002	218.4	108	272	148
003	166	122	182	138
004	52	76	72	92
005	158	injury	140	148
006	144	152	143.2	136
007	228	200	242	196
008	202	208	221.2	216
$\bar{x}$	165.5	148.0	179.7	157.3
± S.E.M.	22.7	18.4	22.7	13.9
AerWt group	N.m.s	N.m.s	N.m.s	N.m.s
009	133.2	190	122	184
010	180	188	194	176
011	274	220	216	204
012	200	202	200	184
013	248	196	226	200
014	139.2	160	145.2	168
015	100	104	107.2	150
016	160	190	140	188
017	126	148	132	128
018	145.2	208	148	162
$\bar{x}$	170.6	180.6	163.0	174.4
± S.E.M	17.6	10.9	13.3	7.3

(iv) a) The percent decline in torque (fatigue index) over 25 consecutive isokinetic single-knee extension contractions

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	% decline	% decline	% decline	% decline
001	30.9	23.1	46.1	53.1
002	36.5	22.2	8.1	2.3
003	37.2	33.4	33.8	34.5
004	46.8	25.3	15.4	18.7
005	27.3	injury	39.1	27.6
006	41.3	43.7	40.5	10.4
007	40.3	37.3	36.8	33.7
008	30.8	22.4	34.1	24.1
$\bar{x}$	37.7	29.6	31.7	25.6
± S.E.M.	2	2.9	4.3	5.2
AerWt group	% decline	% decline	% decline	% decline
009	42	52.8	29.1	22.8
010	39.5	39.5	41.4	30.4
011	30.3	30.5	45.8	44.9
012	51.9	30.9	31.5	29.4
013	37.8	20.6	40.2	26.9
014	32.5	26.8	39.1	22.3
015	46.3	30.9	68.8	27.6
016	48.8	39.2	45.5	39.8
017	29.4	33.2	53.6	30.1
018	15	33.5	35.8	37.9
$\bar{x}$	37.4	33.8	43.1	31.2
± S.E.M.	3.3	2.6	3.5	2.2

(iv) b) The average peak torque (N.m) of the best 3 of the first 5 or 6 contractions in the isokinetic single-knee extension fatigue test

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	N.m	N.m	N.m	N.m
001	117.8	124.5	114.7	131.2
002	112.3	158	109.3	117.3
003	102.3	110.3	146.5	157.8
004	89.8	88.8	81	94.3
005	122.7	injury	131.8	134.3
006	104.2	109	89.5	94.3
007	173.8	198.8	157.3	159
008	187.5	197	219.3	222
$\bar{x}$	126.8	140.9	131.2	138.8
± S.E.M.	13.3	15.5	14.6	13.8
AerWt group	N.m	N.m	N.m	N.m
009	113.3	121.3	101.3	111.7
010	133.3	170.8	131.7	145.5
011	158.8	184.5	148	177.2
012	166.2	188.5	154	151.8
013	176.7	146.7	201.2	157.3
014	142.2	189.2	171.2	200
015	90.7	108.5	105.8	101.3
016	157.2	172.8	146.5	153.3
017	96.7	97.8	102.7	108.5
018	123.2	148.5	138.7	145.8
$\bar{x}$	135.8	152.9	140.1	145.2
± S.E.M.	8.9	10.2	9.6	9.3

(iv) c) The average torque (N.m) of the final 3 contractions in the isokinetic single-knee extension fatigue test

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	N.m	N.m	N.m	N.m
001	81.3	95.7	61.8	61.5
002	71.3	123	100.5	114.6
003	64.2	73.5	97	103.3
004	47.8	66.3	68.5	76.7
005	89.2	injury	80.3	97.3
006	61.2	61.3	53.3	84.5
007	103.7	124.7	99.5	105.5
008	129.8	152.8	144.5	168.5
$\bar{x}$	79.9	99.6	88.2	101.5
± S.E.M.	9.9	12.2	9.6	10.6
AerWt group	N.m	N.m	N.m	N.m
009	65.7	57.3	71.8	86.2
010	80.7	103.3	77.2	101.3
011	110.7	128.2	80.2	97.5
012	79.8	130.2	105.5	107.2
013	110	116.5	120.3	115
014	96	138.5	104.2	155.3
015	48.7	75	33	73
016	80.5	105	79.8	92.3
017	68.3	65.3	47.7	75.8
018	104.7	98.7	89	90.5
$\bar{x}$	84.5	101.8	80.9	99.4
± S.E.M.	6.2	8.4	7.9	7.1

(iv) d) The average torque (N.m) generated over 25 contractions in the isokinetic single-knee extension fatigue test

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	N.m	N.m	N.m	N.m
001	96.9	105.5	90.1	90.8
002	93.3	128.4	103.3	123.4
003	82.9	91.1	122.3	129.2
004	72.1	82.3	77.2	87.4
005	115.8	injury	101.4	113.6
006	74.2	84.7	66.8	74.8
007	144.3	172.3	136.9	140.3
008	162.3	177.5	182.8	191.3
$\bar{x}$	103.7	120.3	110.1	118.9
± S.E.M.	12.4	14.2	12.3	12.2
AerWt group	N.m	N.m	N.m	N.m
009	88.7	94.3	87.7	98.7
010	104.1	133.4	103.7	124.2
011	141.1	160.1	114.1	142.8
012	136.5	160.6	123.6	124.7
013	147.6	119.9	165.5	140.9
014	124.4	171.5	139.4	169.1
015	62.5	84.7	60.8	84.9
016	127.1	139.1	116.7	122.8
017	78.4	83.8	70.6	89.6
018	115	125.3	115.9	124.4
$\bar{x}$	112.5	127.3	109.8	122.2
± S.E.M.	8.5	9.6	9.4	7.7

(iv) e) The single most powerful (N.m) contraction generated in the isokinetic single-knee extension fatigue test

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	N.m	N.m	N.m	N.m
001	123.5	126	115	143
002	127	174	120	143.5
003	105	114	147	167
004	98.5	102	90	101.5
005	139	injury	138.5	139
006	111.5	112.5	99	100
007	178.5	200.5	165.5	164
008	190.5	201.5	224.5	225
$\bar{x}$	133.5	147.2	137.4	147.9
± S.E.M.	12.7	15.2	14.3	13.2
AerWt group	N.m	N.m	N.m	N.m
009	119	124	104	117
010	147	172	143	154
011	166.5	191	150	185
012	170	194	161.5	157
013	180	167	206.5	168
014	144	199	175	216
015	97	110.5	126	102
016	160.5	175	153.5	156.5
017	100	102	105	112.5
018	146	149.5	142	147
$\bar{x}$	143	158.4	146.7	151.5
± S.E.M.	8.7	10.6	9.3	10.4

(iv) f) The Borg scale rating of perceived leg effort at the completion of the isokinetic single-knee extension fatigue test

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	Rating	Rating	Rating	Rating
001	3	3	3	3
002	5	1	5	1
003	4	1	4	2
004	4	5	3	5
005	7	injury	7.5	5
006	3	2	3	3
007	6.5	8	8	8
008	8	8.5	9	8
$\bar{x}$	4.8	4.1	5.3	4.4
± S.E.M.	0.7	1.1	0.9	0.9
AerWt group	Rating	Rating	Rating	Rating
009	2.5	2	3	2
010	3	2	3	2
011	2	0.5	4.5	1
012	3	1	3	3
013	4	0.5	3	0.5
014	3	3	3	2
015	3	2.5	3	2
016	3	4	3	4
017	4	4	3	2
018	5	5	8	2
$\bar{x}$	3.3	2.5	3.7	2.1
± S.E.M.	0.3	0.5	0.5	0.3

(iv) g) The Borg scale rating of perceived breathing effort at the completion of the isokinetic single-knee extension fatigue test

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	Rating	Rating	Rating	Rating
001	0	0	0	0
002	3	0	3	0
003	3	0.5	3	0
004	3	4	3.5	4
005	4	injury	4.5	6
006	0.5	0.5	1	0.5
007	6.5	5	7	4
008	4	4	4	4
$\bar{x}$	2.9	2	3.3	2.3
± S.E.M.	0.8	0.8	0.8	0.9
AerWt group	Rating	Rating	Rating	Rating
009	0	0	0.5	0
010	0.5	1	0.5	0
011	1	0.5	3	0.5
012	0.5	0	1	0
013	3	0	1	0
014	2	1	2	1
015	1	0.5	2	0.5
016	3	1	3	2
017	3	5	3	0
018	1	3	4	0.5
$\bar{x}$	1.5	1.2	2	0.5
± S.E.M.	0.4	0.5	0.4	0.2

(iv) h) The Borg scale rating of perceived chest discomfort at the completion of the isokinetic single-knee extension fatigue test

Subject	Right Pre-	Right Post-	Left Pre-	Left Post-
Aer group	Rating	Rating	Rating	Rating
001	0	0	0	0
002	0	0	0	0
003	0	0	0	0
004	0	2	0.5	1
005	3	injury	1	0
006	0	0	0.5	0
007	0	0	0	0
008	1.5	1	1	0
$\bar{x}$	0.2	0.4	0.4	0.1
± S.E.M.	0.2	0.3	0.2	0.1
AerWt Group	Rating	Rating	Rating	Rating
009	0	0	0	0
010	0.5	0	0.5	0
011	0	0	0	0
012	0	0	0	0
013	0	0	0	0
014	0	0	0	0
015	0	0	0	0
016	0	0	0	0
017	0	0	0	0
018	0.5	0	0.5	0
$\bar{x}$	0.1	0	0.1	0
± S.E.M.	0.06	0	0.06	0

(v) a) Maximum power output in a progressive incremental cycle ergometer exercise test

Subject	Pre-training Maximum Power	Post-training Maximum Power
Aer group	kpm/min	kpm/min
001	1000	1100
002	900	1000
003	1000	1000
004	800	800
005	1300	1300
006	1100	1100
007	1300	1300
008	1300	1300
$\bar{x}$	1088	1113
± S.E.M.	65	60
AerWt group	kpm/min	kpm/min
009	1100	1100
010	1000	1200
011	1300	1400
012	1200	1300
013	1100	1400
014	1000	1300
015	700	1000
016	1100	1200
017	700	800
018	1100	1100
$\bar{x}$	1030	1180
± S.E.M.	58	56

(v) b) Maximum power output in a progressive incremental cycle ergometer test expressed as percent predicted for a healthy control population

Subject	Pre-training	Post-training
Aer group	% of predicted	% of predicted
001	92	102
002	80	89
003	93	93
004	69	70
005	98	98
006	95	95
007	98	98
008	88	88
$\bar{x}$	89	92
± S.E.M.	3.3	3.3
Aer Wt group	% of predicted	% of predicted
009	86	86
010	78	95
011	104	113
012	88	95
013	84	104
014	83	109
015	59	85
016	93	102
017	69	79
018	90	90
$\bar{x}$	83	96
± S.E.M.	3.8	3.3

(v) c) The rating of perceived leg exertion (RPLE) during progressive incremental cycle ergometer exercise at each absolute workload in the Aer group

Subj.	100 kpm/min		200 kpm/min		300 kpm/min		400 kpm/min		500 kpm/min		600 kpm/min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	0	0	0	0	0	0	0	0	.5	.5	.75	.5
002	0	0	0	1	0	2	2	3	3	3	3	4
003	0	0	0	0	0	0	0	.5	.5	.5	.5	1
004	0	0	0	0	0	0	0	1	5	3	5	3
005	0	0	0	0	0	0	0	0	0	0	.5	.5
006	0	0	0	0	0	0	.5	0	.5	.5	1	1
007	0	0	.5	0	.5	.5	1	2	1	2	1	3
008	0	0	0	0	0	0	1	.5	2	1	3	2
$\bar{x}$ Pre	0		0.1		0.1		0.6		1.6		1.8	
SEM	0		0.1		0.1		0.3		0.6		0.6	
$\bar{x}$ Post	0		0.1		0.3		0.9		1.3		1.9	
SEM	0		0.1		0.3		0.4		0.4		0.5	

Subj.	700 kpm/min		800 kpm/min		900 kpm/min		1000 kpm/min		1100 kpm/min		1200 kpm/min		1300 kpm/min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	3	1	3.5	2	5	3	5	4	/	6.5	/	/	/	/
002	4	4	5	5	7	7	/	9	/	/	/	/	/	/
003	1	1	1	1	1	3	3	7	/	/	/	/	/	/
004	5	4	5	5	/	/	/	/	/	/	/	/	/	/
005	1	.5	1	1	3	2	5	4	7	6	7	8	10	9
006	2	1	3	3	5	5	7	7	9	8	/	/	/	/
007	2	4	3	5	3.5	6	5	7	6	8	8	9	9	10
008	5	3	7	4	8	5	9	6	10	9	10	10	10	10
$\bar{x}$ Pre	2.9		3.6		4.6		5.7		8.0		8.3		9.7	
SEM	0.6		0.7		0.9		0.8		0.9		1.5		0.6	
$\bar{x}$ Post	2.3		3.3		4.4		6.3		7.5		9.0		9.7	
SEM	0.6		0.6		0.7		0.7		0.6		1.0		0.6	

(v) d) The rating of perceived leg exertion (RPLE) during progressive incremental cycle ergometer exercise at each absolute workload in the AerWt group

Subj.	100 kpm/ min		200 kpm/ min		300 kpm/ min		400 kpm/ min		500 kpm/ min		600 kpm/ min		700 kpm/ min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	0	0	0	0	0	0	0	0	0	.5	2	2	3	3
002	.5	0	.5	0	.5	.5	.5	.5	1	1	2	1	3	2
003	0	0	0	0	0	0	.5	0	.5	.5	2	.5	3	1
004	0	0	0	0	.5	0	.5	0	1	0	2	.5	2	1
005	0	0	0	0	0	0	0	0	0	0	0	0	.5	0
006	0	0	0	0	0	0	.5	.5	2	2	4	3	5	3
007	0	0	0	0	0	0	0	0	.5	.5	1	.5	2	2
008	0	0	0	0	0	0	0	0	1	0	2	.5	3	.5
009	0	0	0	0	0	0	1	.5	3	1	6	3	7	3
010	0	0	0	0	.5	0	.5	.5	1	.5	2	1	3	2
$\bar{x}$ Pre	0.1		0.1		0.2		0.4		1.0		2.3		3.2	
SEM	0.1		0.1		0.1		0.1		0.3		0.1		0.6	
$\bar{x}$ Post	0		0		0.1		0.2		0.6		1.2		1.8	
SEM	0		0		0.1		0.1		0.2		0.3		0.3	

Subj.	800 kpm/ min		900 kpm/ min		1000 kpm/ min		1100 kpm/ min		1200 kpm/ min		1300 kpm/ min		1400 kpm/ min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	3	3.5	4	4	5	5	7	10	/	/	/	/	/	/
002	3	3	4	3	5	4	/	5	/	5	/	/	/	/
003	3	1	4	2	4	2.5	4.5	4	7	4	10	6	/	9
004	3	2	4	3	5	4	7.5	6	9	8	/	10	/	/
005	1.5	.5	2.5	.5	3	.5	5	1	/	3	/	4	/	7
006	7	4	9	5	10	5	/	8	/	9	/	10	/	/
007	/	3	/	4	/	4	/	/	/	/	/	/	/	/
008	4	1	6	1	7	3	9	3	/	7	/	/	/	/
009	/	4	/	/	/	/	/	/	/	/	/	/	/	/
010	4	3	5	4	7	5	8.5	6	/	/	/	/	/	/
$\bar{x}$ Pre	3.6		4.8		5.6		6.9		8.0		10		/	
SEM	0.6		0.7		0.8		0.8		0.8		0		/	
$\bar{x}$ Post	2.5		2.9		3.7		5.4		6.0		7.5		8.0	
SEM	0.4		0.5		0.5		1.0		1.0		1.5		1.2	

(v) e) **The rating of perceived breathing effort during progressive incremental cycle ergometer exercise at each absolute workload in the Aer group**

Subj.	100 kpm/min		200 kpm/min		300 kpm/min		400 kpm/min		500 kpm/min		600 kpm/min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	0	0	0	0	0	0	0	0	.5	0	1	.5
002	0	0	.5	1	.5	2	1	3	2	3	3	4
003	0	0	0	0	0	0	0	0	0	.5	0	.5
004	0	.5	0	.5	0	1	1	3	2	4	3	4
005	0	0	0	0	0	0	0	0	0	0	0	.5
006	0	0	0	0	0	0	0	0	0	.5	.5	1
007	.5	1	.5	1	1	1	1	2	1	2	1	3
008	0	0	0	0	0	0	.5	.5	1	1	2	1.5
$\bar{x}$ Pre	0.1		0.1		0.2		0.4		0.8		1.3	
SEM	0.1		0.1		0.1		0.2		0.3		0.4	
$\bar{x}$ Post	0.2		0.3		0.5		1.1		1.4		1.9	
SEM	0.1		0.2		0.3		0.5		0.5		0.6	

Subj.	700 kpm/min		800 kpm/min		900 kpm/min		1000 kpm/min		1100 kpm/min		1200 kpm/min		1300 kpm/min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	3	1	3.5	2	3.5	2	5	4	/	5	/	/	/	/
002	4	4	5	4	9	6	/	7	/	/	/	/	/	/
003	0	1	.5	1	.5	2	2	4	/	/	/	/	/	/
004	4	5	5	6	/	/	/	/	/	/	/	/	/	/
005	1	.5	1	1	3	2	5	4	7	6	7	8	10	9
006	2	1	3	2	5	3	5	5	6	5	/	/	/	/
007	2	4	3	5	3.5	7	4	7	6	9	7	10	9	10
008	3.5	2	5	3.5	6	5	7	6	8	8.5	9	9.5	10	10
$\bar{x}$ Pre	2.4		3.3		4.4		4.7		6.8		7.7		9.7	
SEM	0.5		0.6		1.0		0.7		0.5		0.7		0.3	
$\bar{x}$ Post	2.3		3.1		3.9		5.3		6.7		9.2		9.7	
SEM	0.6		0.7		0.8		0.5		0.9		0.6		0.3	

(v) f) The rating of perceived breathing effort during progressive incremental cycle ergometer at each absolute work load in the AerWt group

Subj.	100 kpm/ min		200 kpm/ min		300 kpm/ min		400 kpm/ min		500 kpm/ min		600 kpm/ min		700 kpm/ min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	/	/	/	/	/	/	/	/	/	/	/	/	/	/
002	0	0	0	0	0	.5	.5	.5	.5	.5	1	1	2	1
003	0	0	0	0	0	0	0	0	0	0	.5	.5	1	.5
004	0	0	0	0	0	0	0	0	0	0	.5	0	.5	0
005	0	0	0	0	0	0	0	0	0	0	0	0	0	0
006	0	0	0	0	0	0	.5	1	2	2	3	3	3	3
007	0	0	0	0	0	0	0	0	1	.5	1	.5	3	1
008	0	0	0	0	.5	0	.5	.5	1	1	3	3	4	4
009	0	0	0	0	0	0	1	.5	2	1	5	3	6	3
010	0	0	.5	0	.5	.5	.5	.5	.5	.5	1	1	1	1
x̄ Pre	0		0.1		0.1		0.3		0.8		1.7		2.3	
SEM	0		0.1		0.1		0.1		0.3		0.6		0.6	
x̄ Post	0		0		0.1		0.3		0.6		1.3		1.5	
SEM	0		0		0.1		0.1		0.2		0.4		0.5	

Subj.	800 kpm/ min		900 kpm/ min		1000 kpm/ min		1100 kpm/ min		1200 kpm/ min		1300 kpm/ min		1400 kpm/ min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	/	/	/	/	/	/	/	/	/	/	/	/	/	/
002	3	1	3	2	3	3	/	3	/	4	/	/	/	/
003	.5	.5	2	1	3	2	3	3	4	3	7	4	/	6
004	1	.5	1	1	2	2	4	3	7	4	/	6.5	/	/
005	1	.5	1	.5	1	1	4.5	1	/	2	/	3	/	6
006	4	4	5	4	7	5	/	7	/	8	/	9	/	/
007	/	2	/	4	/	5	/	/	/	/	/	/	/	/
008	5	5	7	7	7.5	7	9	7	/	9	/	/	/	/
009	/	4	/	/	/	/	/	/	/	/	/	/	/	/
010	3	2	4	3	4	3	4.5	4	/	/	/	/	/	/
x̄ Pre	2.5		3.3		3.9		5.0		5.5		7.0		/	
SEM	0.7		0.8		0.9		1.0		1.5		0		/	
x̄ Post	2.2		2.8		3.5		4.0		5.0		5.6		6	
SEM	0.6		0.8		0.7		0.9		1.2		1.3		0	

(v) g) The rating of perceived chest discomfort during progressive incremental cycle ergometer exercise at each absolute workload in the Aer group

Subj.	100 kpm/ min		200 kpm/ min		300 kpm/ min		400 kpm/ min		500 kpm/ min		600 kpm/ min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	0	0	0	0	0	0	0	0	0	0	0	0
002	0	0	0	0	0	2	0	0	0	0	0	0
003	0	0	0	0	0	0	0	0	0	0	0	0
004	0	0	0	0	0	0	0	0	0	0	0	0
005	0	0	0	0	0	0	0	0	0	0	0	0
006	0	0	0	0	0	0	0	0	0	0	.5	0
007	0	0	0	0	0	0	0	0	0	0	0	0
008	0	0	0	0	0	0	0	0	.5	0	.5	0
$\bar{x}$ Pre	0		0		0		0		0.1		0.1	
SEM	0		0		0		0		0.1		0.1	
$\bar{x}$ Post	0		0		0.3		0		0		0	
SEM	0		0		0.2		0		0		0	

Subj.	700 kpm/ min		800 kpm/ min		900 kpm/ min		1000 kpm/ min		1100 kpm/ min		1200 kpm/ min		1300 kpm/ min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	0	0	0	0	0	0	0	0	/	0	/	/	/	/
002	0	0	0	0	0	0	/	0	/	/	/	/	/	/
003	0	0	0	0	.5	0	0	0	/	/	/	/	/	/
004	0	0	0	0	/	/	/	/	/	/	/	/	/	/
005	0	0	0	0	0	.5	.5	1	1	1	1	2	1	4
006	1	0	1	0	1	0	2	0	2	0	/	/	/	/
007	0	0	0	0	0	0	0	0	0	0	0	0	0	0
008	1	0	1	.5	2	1	3	1.5	3	1.5	3	2	3	3
$\bar{x}$ Pre	0.3		0.3		0.5		0.9		1.5		1.3		1.3	
SEM	0.2		0.2		0.3		0.5		0.7		0.7		0.7	
$\bar{x}$ Post	0		0.1		0.2		0.4		0.5		1.3		2.3	
SEM	0		0.1		0.2		0.2		0.3		0.5		0.9	

(v) h) The rating of perceived chest discomfort during progressive incremental cycle ergometer exercise at each absolute workload in the AerWt group

Subj.	100 kpm/ min		200 kpm/ min		300 kpm/ min		400 kpm/ min		500 kpm/ min		600 kpm/ min		700 kpm/ min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
002	0	0	0	0	0	0	0	0	0	0	0	0	0	0
003	0	0	0	0	0	0	0	0	0	0	.5	0	.5	0
004	0	0	0	0	0	0	0	0	0	0	0	0	0	0
005	0	0	0	0	0	0	0	0	0	0	0	0	0	0
006	0	0	0	0	0	0	0	0	1	0	2	0	2	0
007	0	0	0	0	0	0	0	0	.5	0	.5	0	.5	0
008	0	0	0	0	0	0	0	0	0	0	0	0	0	0
009	0	0	0	0	0	0	0	0	0	.5	2	2	2	3
010	0	0	0	0	0	0	0	0	0	0	.5	0	2	0
$\bar{x}$ Pre	0		0		0		0		0.2		0.6		0.7	
SEM	0		0		0		0		0.1		0.3		0.3	
$\bar{x}$ Post	0		0		0		0		0.1		0.2		0.3	
SEM	0		0		0		0		0.1		0.2		0.3	

Subj.	800 kpm/ min		900 kpm/ min		1000 kpm/ min		1100 kpm/ min		1200 kpm/ min		1300 kpm/ min		1400 kpm/ min	
	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO	PR	PO
001	0	0	0	0	0	0	0	0	/	/	/	/	/	/
002	0	0	0	0	0	0	/	0	/	0	/	/	/	/
003	0	0	.5	0	.5	0	0	0	0	0	0	0	/	0
004	0	0	0	0	0	0	0	0	0	0	/	0	/	/
005	0	0	0	0	0	0	0	0	/	0	/	0	/	0
006	2	0	2	0	3	0	/	0	/	0	/	0	/	/
007	/	0	/	0	/	0	/	/	/	/	/	/	/	/
008	0	0	.5	0	1	.5	1	1	/	3	/	/	/	/
009	/	6	/	/	/	/	/	/	/	/	/	/	/	/
010	3	0	2	0	2	0	3	0	/	/	/	/	/	/
$\bar{x}$ Pre	0.6		0.6		0.8		0.7		0		0		/	
SEM	0.4		0.3		0.4		0.5		0		0		/	
$\bar{x}$ Post	0.6		0		0.1		1.4		0.5		0		0	
SEM	0.6		0		0.1		1.2		0.5		0		0	

(vi) a) Submaximal endurance time in seconds to a Borg scale leg effort rating of 4 at 80% of initial Wmax

Subject	Pre-training	Post-training
Aer group	seconds	seconds
001	520	540
002	244	410
003	532	671
004	260	240
005	215	injury
006	430	400
007	230	235
008	260	300
$\bar{x}$	354	399
± S.E.M.	47	56
AerWt group	seconds	seconds
009	209	130
010	285	460
011	240	598
012	401	775
013	770	935
014	227	480
015	420	1050
016	410	1484
017	266	525
018	271	400
$\bar{x}$	350	684
± S.E.M.	50.2	116.5

(vi) b) Submaximal endurance time to a Borg scale leg effort rating of 7 at 80% of initial Wmax

Subject	Pre-training	Post-training
Aer group	seconds	seconds
001	645	855
002	351	895
003	1210	855
004	542	595
005	535	injury
006	520	545
007	480	470
008	480	490
$\bar{x}$	604	672
± S.E.M.	98	66
AerWt group	seconds	seconds
009	405	420
010	525	570
011	382	790
012	467	885
013	955	1230
014	355	1800
015	720	2400
016	765	1925
017	386	600
018	449	660
$\bar{x}$	541	1128
± S.E.M.	61	205

(vii) a) The time (seconds) to complete each ascent (36 stairs) in the stair climbing exercise

Subject	Pre- Day 1	Post- Day 1	Post- Day 2
Aer group	seconds	seconds	seconds
001	23	26	26
002	28	27	27
003	18	22	18
004	26	25	24
005	22	injury	injury
006	25	26	24
007	21	23	24
008	24	23	26
$\bar{x}$	23.6	24.6	24.1
± S.E.M.	1.2	0.7	1.0
AerWt group	seconds	seconds	seconds
009	24	24	25
010	28	26	27
011	22	22	24
012	21	22	19
013	21	24	26
014	25	27	30
015	27	27	28
016	17	20	18
017	21	25	23
018	26	25	26
$\bar{x}$	23.2	24.2	24.6
± S.E.M.	1.0	0.7	1.1

(vii) b) The resting heart rate (bpm) prior to, and exercise heart rate (bpm) upon completion of, the stair climbing exercise

Subject	Pre-Day 1 Rest	Pre-Day 1 Exer.	Post-Day 1 Rest	Post Day 1 Exer.	Post Day 2 Rest	Post Day 2 Exer.
Aer	bpm	bpm	bpm	bpm	bpm	bpm
001	56	72	68	88	68	96
002	68	88	72	104	68	100
003	64	88	60	84	68	92
004	84	108	84	108	84	112
005	48	88	injury	injury	injury	injury
006	76	116	76	96	80	116
007	64	92	76	96	64	100
008	80	116	68	100	68	96
$\bar{x}$	70	97	72	97	71	102
± S.E.M	4	6	3	3	3	3
AerWt	bpm	bpm	bpm	bpm	bpm	bpm
009	52	92	68	96	64	88
010	92	112	80	112	84	112
011	92	124	72	116	80	104
012	68	100	64	104	64	100
013	68	84	68	92	60	84
014	84	116	76	124	80	120
015	64	92	64	88	68	84
016	92	120	80	108	92	124
017	80	104	88	116	80	104
018	72	88	72	88	64	92
$\bar{x}$	76	103	73	104	74	101
± S.E.M	4	4	2	4	3	4

(vii) c) The Borg scale rating of perceived leg effort at the completion of the stair climbing exercise

Subject	Pre- Day 1	Post- Day 1	Post- Day 2
Aer group	Rating	Rating	Rating
001	0.5	1	1
002	3	1	0.5
003	0.5	0.5	1.5
004	4	5	5
005	1	injury	injury
006	1	0.5	1.5
007	0.5	1	1
008	1	1.5	2
x	1.5	1.5	1.8
± S.E.M.	0.5	0.6	0.5
AerWt group	Rating	Rating	Rating
009	0.5	1	1
010	0.5	0.5	0.5
011	0.5	0.5	0.5
012	0.5	0.5	0.5
013	0.5	0.5	0.5
014	1	1	0.5
015	4.5	3	2
016	0.5	1	1
017	0.5	0.5	0.5
018	0.5	1	1
x	0.95	0.95	0.8
± S.E.M.	0.4	0.2	0.2

(vii) d) The Borg scale rating of perceived breathing effort at the completion of the stair climbing exercise

Subject	Pre- Day 1	Post- Day 1	Post- Day 2
Aer group	Rating	Rating	Rating
001	0	0	0
002	4	1	0.5
003	0	0	0.5
004	4	4	4
005	1	injury	injury
006	0.5	0	0.5
007	2.5	3	1.5
008	3	2.5	3
$\bar{x}$	2	1.5	1.4
± S.E.M.	0.6	0.6	0.5
AerWt group	Rating	Rating	Rating
009	0	0	0
010	1	0.5	0
011	0	0.25	0.5
012	1	1	0.5
103	2.5	0.5	0.5
014	0	1	0
015	3.5	1.5	1
016	1	2	2
017	0	0.5	0
018	0	0.5	0.5
$\bar{x}$	0.9	0.8	0.5
± S.E.M.	0.4	0.2	0.2

(vii) e) The Borg scale rating of perceived chest discomfort at the completion of the stair climbing exercise

Subject	Pre- Day 1	Post- Day 1	Post- Day 2
Aer group	Rating	Rating	Rating
001	0	0	0
002	0	0	0
003	0	0	0
004	0	0	0
005	1	injury	injury
006	0.5	0	0
007	0	0	0
008	1	0.5	0
$\bar{x}$	0.2	0.07	0
± S.E.M.	0.1	0.07	0
AerWt group	Rating	Rating	Rating
009	0	0	0
010	0	0	0
011	0	0	0
012	0	0	0
013	0	0	0
914	0	0	0
015	0	0	0
016	0	0	0
017	0	0	0
018	0	0	0
$\bar{x}$	0	0	0
± S.E.M.	0	0	0

APPENDIX F: PATIENT CHARACTERISTICS

(i) a) Description of each subject by age, height, weight, and disease category

Subject	Age	Height	Weight	Disease Category
Aer group	years	cm.	kg.	MI= myocardial infarction CABG= coronary artery bypass graft
001	55	170	75.5	MI
002	61	174.5	96.3	MI
003	56	170	82.8	Exertional Angina
004	65	178	88	MI
005	50	180	80.5	MI
006	39	167	63	MI
007	50	180	92	MI
008	41	183	79	MI
$\bar{x}$	52	175	82	7 MI, 1 Exer. Angina
± S.E.M.	3.2	2.1	3.7	
AerWt group	years	cm.	kg.	MI, CABG and\or Exer. Angina
009	40	173	88	MI
010	46	176	102	MI
011	48	175	97	MI
012	42	179	80	MI
013	48	178	100	MI
014	48	173	79	MI and CABG
015	56	175	97	MI
016	65	179	86	MI
017	58	168	68	MI and CABG
018	40	170	76	MI
$\bar{x}$	49	175	87	10 MI and 2 CABG
± S.E.M.	2.5	1.2	3.6	

APPENDIX G: ANALYSIS OF VARIANCE TABLES

(i) a) The maximum weight lifted (1RM) in single- arm curl exercise

Source	SS	df	MS	F	p
Group[a]	87.9	1	87.9	3.26	N.S.
Subj. W. Groups	430.9	16	26.9		
Time	192.9	1	192.9	138.0	<0.01
Group x Time	58.2	1	58.2	41.7	<0.01
Time x S.W.G.	22.4	16	1.4		
Limb[b]	51.8	1	51.8	24.6	<0.01
Group x Limb	2.6	1	2.6	1.2	N.S.
Limb x S.W.G.	33.7	16	2.1		
Time x Limb	0.9	1	0.9	2.1	N.S.
Group x Time x Limb	0.05	1	0.05	0.1	N.S.
Time x Limb x S.W.G.	6.6	16	0.4		

[a] Includes eight Aer and ten AerWt subjects.

[b] Includes right and left arms.

(i) b) The maximum weight lifted (1RM) in single- knee extension exercise

Source	SS	df	MS	F	p
Group[a]	204.6	1	204.6	0.65	N.S.
Subj. W. Groups	4705.4	15	313.7		
Time	302.4	1	302.4	81.39	<0.01
Group x Time	129.4	1	129.4	34.82	<0.01
Time x S.W.G.	55.7	15	3.7		
Limb[b]	7.6	1	7.6	1.2	N.S.
Group x Limb	0.6	1	0.6	0.098	N.S.
Limb x S.W.G.	95.2	15	6.4		
Time x Limb	0.004	1	0.0037	0.004	N.S.
Group x Time x Limb	0.028	1	0.028	0.026	N.S.
Time x Limb x S.W.G.	16.2	15	1.1		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(i) c) The maximum weight lifted (1RM) in single- leg press exercise

Source	SS	df	MS	F	p
Group[a]	1798.9	1	1798.9	1.62	N.S.
Subj. W. Groups	16641.3	15	1109.4		
Time	2604.9	1	2604.9	57.9	<0.01
Group x Time	1083.7	1	1083.7	24.1	<0.01
Time x S.W.G.	674.8	15	44.9		
Limb[b]	201.4	1	201.4	2.5	N.S.
Group x Limb	75.5	1	75.5	0.9	N.S.
Limb x S.W.G.	1226.5	15	81.8		
Time x Limb	0.9	1	0.9	0.4	N.S.
Group x Time x Limb	13.6	1	13.6	5.9	<0.05
Time x Limb x S.W.G.	34.3	15	2.3		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) a) The peak torque (N.m) generated in isokinetic single- knee extension exercise at an angular velocity of 90°/s

Source	SS	df	MS	F	p
Group[a]	2729.9	1	2729.9	0.64	N.S.
Subj. W. Groups	63596.5	15	4239.8		
Time	1105.5	1	1105.5	8.64	<0.05
Group x Time	404.7	1	404.7	3.16	N.S.
Time x S.W.G.	1919.3	15	127.9		
Limb[b]	1660.8	1	1660.8	4.89	<0.05
Group x Limb	238.7	1	238.7	0.70	N.S.
Limb x S.W.G.	5089.6	15	339.3		
Time x Limb	34.2	1	34.2	0.99	N.S.
Group x Time x Limb	9.7	1	9.7	0.28	N.S.
Time x Limb x S.W.G.	513.8	15	34.3		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) b) The peak torque (N.m) generated in isokinetic single- knee extension exercise at an angular velocity of 180°/s

Source	SS	df	MS	F	p
Group[a]	2350.5	1	2350.5	0.72	N.S.
Subj. W. Groups	48800.3	15	3253.4		
Time	785.6	1	785.6	5.23	<0.05
Group x Time	362.9	1	362.9	2.41	N.S.
Time x S.W.G.	2254.3	15	150.3		
Limb[b]	2570.6	1	2570.6	6.79	<0.05
Group x Limb	1551.9	1	1551.9	4.10	N.S.
Limb x S.W.G.	5677.3	15	378.5		
Time x Limb	115.4	1	115.4	3.19	N.S.
Group x Time x Limb	0.13	1	0.13	0.004	N.S.
Time x Limb x S.W.G.	542.0	15	36.13		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) c) The average torque (N.m) generated in isokinetic single- knee extension exercise at an angular velocity of 90°/s

Source	SS	df	MS	F	p
Group[a]	168.6	1	168.6	0.091	N.S.
Subj. W. Groups	27784.3	15	1852.3		
Time	190.3	1	190.3	0.64	N.S.
Group x Time	386.3	1	386.3	1.29	N.S.
Time x S.W.G.	4480.7	15	298.7		
Limb[b]	3.2	1	3.2	0.029	N.S.
Group x Limb	0.26	1	0.26	0.002	N.S.
Limb x S.W.G.	1613.4	15	107.6		
Time x Limb	13.2	1	13.2	0.23	N.S.
Group x Time x Limb	26.9	1	26.9	0.46	N.S.
Time x Limb x S.W.G.	871.4	15	58.1		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) d) The average torque (N.m) generated in isokinetic single- knee extension exercise at an angular velocity of 180°/s

Source	SS	df	MS	F	p
Group[a]	677.9	1	677.9	0.72	N.S.
Subj. W. Groups	14230.7	15	948.7		
Time	131.1	1	131.1	0.94	N.S.
Group x Time	114.4	1	114.4	0.82	N.S.
Time x S.W.G.	2088.2	15	139.2		
Limb[b]	457.1	1	457.1	6.09	<0.05
Group x Limb	130.5	1	130.5	1.74	N.S.
Limb x S.W.G.	1124.7	15	74.9		
Time x Limb	31.1	1	31.1	0.62	N.S.
Group x Time x Limb	10.9	1	10.9	0.22	N.S.
Time x Limb x S.W.G.	756.0	15	50.4		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) e) The impulse (N.m.s) generated in isokinetic single-knee extension exercise at an angular velocity of 90°/s

Source	SS	df	MS	F	p
Group	84.3	1	84.3	0.049	N.S.
Subj. W. Groups	25532.8	15	1702.2		
Time	74.7	1	74.7	0.27	N.S.
Group x Time	72.1	1	72.1	0.26	N.S.
Time x S.W.G.	4149.7	15	276.7		
Limb	459.0	1	459.0	4.28	N.S.
Group x Limb	15.6	1	15.6	0.15	N.S.
Limb x S.W.G.	1608.8	15	107.3		
Time x Limb	20.6	1	20.6	0.33	N.S.
Group x Time x Limb	90.9	1	90.9	1.44	N.S.
Time x Limb x S.W.G.	946.0	15	63.1		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) f) The impulse (N.m.s) generated in isokinetic single-knee extension exercise at an angular velocity of 180°/s

Source	SS	df	MS	F	p
Group[a]	104.6	1	104.6	0.49	N.S.
Subj. W. Groups	3189.7	15	212.7		
Time	9.3	1	9.3	0.34	N.S.
Group x Time	2.8	1	2.8	0.10	N.S
Time x S.W.G.	417.4	15	27.8		
Limb[b]	206.1	1	206.1	8.22	<0.05
Group x Limb	2.3	1	2.3	0.09	N.S.
Limb x S.W.G.	376.1	15	25.1		
Time x Limb	0.028	1	0.028	0.004	N.S.
Group x Time x Limb					N.S.
Time x Limb x S.W.G.	107.5	15	7.2		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) g) The peak torque (N.m) generated in isokinetic single- leg press exercise at an angular velocity of 30°/s

Source	SS	df	MS	F	p
Group[a]	131414.7	1	131414.7	3.04	N.S.
Subj. W. Groups	647760.0	15	43184.0		
Time	5735.9	1	5735.9	3.43	N.S.
Group x Time	1155.0	1	1155.0	0.69	N.S.
Time x S.W.G.	25112.0	15	1674.1		
Limb[b]	125.6	1	125.6	0.063	N.S.
Group x Limb	6843.5	1	6843.5	3.42	N.S.
Limb x S.W.G.	30060.0	15	2004.0		
Time x Limb	2972.9	1	2972.9	5.38	<0.05
Group x Time x Limb	594.9	1	594.9	1.08	N.S
Time x Limb x S.W.G.	8284.0	15	552.3		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) h) The peak torque (N.m) generated in isokinetic single- leg press exercise at an angular velocity of 75°/s

Source	SS	df	MS	F	p
Group[a]	46103.2	1	46103.2	1.17	N.S.
Subj. W. Groups	589147.0	15	39276.5		
Time	5188.2	1	5188.2	6.64	<0.05
Group x Time	990.3	1	990.3	1.27	N.S.
Time x S.W.G.	11720.0	15	781.3		
Limb[b]	265.6	1	265.6	0.21	N.S.
Group x Limb	5872.8	1	5872.8	4.73	<0.05
Limb x S.W.G.	18626.0	15	1241.7		
Time x Limb	407.7	1	407.7	1.64	N.S.
Group x Time x Limb					N.S.
Time x Limb x S.W.G.	3731.0	15	248.7		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) i) The average torque (N.m) generated in isokinetic single- leg press at an angular velocity of 30°/s

Source	SS	df	MS	F	p
Group[a]	17257.1	1	17257.1	1.35	N.S.
Subj. W. Groups	192357.5	15	12823.8		
Time	171.4	1	171.4	0.49	N.S.
Group x Time	2503.0	1	2503.0	7.25	<0.05
Time x S.W.G.	5176.5	15	345.1		
Limb[b]	518.8	1	518.8	0.61	N.S.
Group x Limb	1289.9	1	1289.9	1.51	N.S.
Limb x S.W.G.	12788.0	15	852.5		
Time x Limb	2495.8	1	2495.8	6.66	<0.05
Group x Time x Limb	39.6	1	39.6	0.11	N.S.
Time x Limb x S.W.G.	5619.5	15	374.6		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) j) **The average torque (N.m) generated in isokinetic single- leg press exercise at an angular velocity of 75°/s**

Source	SS	df	MS	F	p
Group[a]	6953.7	1	6953.7	0.56	N.S.
Subj. W. Groups	185728.0	15	12381.9		
Time	403.5	1	403.5	0.80	N.S.
Group x Time	3623.5	1	3623.5	7.19	<0.05
Time x S.W.G.	7554.0	15	503.6		
Limb[b]	8.2	1	8.2	0.037	N.S.
Group x Limb	2597.7	1	2597.7	11.75	<0.01
Limb x S.W.G.	3315.0	15	221.0		
Time x Limb	3.6	1	3.6	0.027	N.S.
Group x Time x Limb	106.0	1	106.0	0.78	N.S.
Time x Limb x S.W.G.	2034.5	15	135.6		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) k) The impulse (N.m.s) generated in isokinetic single-leg press exercise at an angular velocity of 30°/s

Source	SS	df	MS	F	p
Group[a]	1571.9	1	1571.9	0.036	N.S.
Subj. W. Groups	650463.0	15	43364.2		
Time	318.1	1	318.1	0.031	N.S.
Group x Time	23679.6	1	23679.6	2.27	N.S.
Time x S.W.G.	156521.0	15	10434.7		
Limb[b]	10386.8	1	10386.8	4.50	<0.05
Group x Limb	3719.3	1	3719.3	1.61	N.S.
Limb x S.W.G.	34599.0	15	2306.6		
Time x Limb	4172.2	1	4172.2	5.67	<0.05
Group x Time x Limb	170.9	1	170.9	0.23	N.S.
Time x Limb x S.W.G.	11031.0	15	735.4		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(ii) 1) The impulse (N.m.s) generated in isokinetic single-leg press exercise at an angular velocity of 75°/s

Source	SS	df	MS	F	p
Group[a]	1000.2	1	1000.2	0.15	N.S.
Subj. W. Groups	102903.3	15	6860.2		
Time	539.0	1	539.0	0.34	N.S.
Group x Time	4441.7	1	4441.7	2.81	N.S.
Time x S.W.G.	23675.6	15	1578.4		
Limb[b]	288.4	1	288.4	1.03	N.S.
Group x Limb	2008.9	1	2008.9	7.18	<0.05
Limb x S.W.G.	4199.1	15	279.9		
Time x Limb	66.0	1	66.0	0.46	N.S.
Group x Time x Limb	116.5	1	116.5	0.81	N.S.
Time x Limb x S.W.G.	2156.6	15	143.8		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(iii) a) The percent decline in torque (fatigue index) over 25 consecutive isokinetic single- knee extension contractions

Source	SS	df	MS	F	p
Group[a]	506.4	1	506.4	3.58	N.S.
Subj. W. Groups	2119.8	15	141.3		
Time	861.4	1	861.4	11.25	<0.01
Group x Time	3.9	1	3.9	0.05	N.S.
Time x S.W.G.	1148.3	15	76.6		
Limb[b]	69.9	1	69.9	0.39	N.S.
Group x Limb	217.5	1	217.5	1.20	N.S.
Limb x S.W.G.	2717.6	15	181.2		
Time x Limb	32.9	1	32.9	0.51	N.S.
Group x Time x Limb	123.2	1	123.2	1.92	N.S.
Time x Limb x S.W.G.	964.9	15	64.3		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(iii) b) <u>The average torque (N.m) generated over 25 contractions in the isokinetic single- knee extension fatigue test</u>

Source	SS	df	MS	F	p
Group[a]	293.8	1	293.8	0.073	N.S.
Subj. W. Groups	60421.6	15	4028.1		
Time	2775.8	1	2775.8	14.22	<0.01
Group x Time	5.5	1	5.5	0.03	N.S.
Time x S.W.G.	2927.4	15	195.2		
Limb[b]	0.77	1	0.77	0.003	N.S.
Group x Limb	224.4	1	224.4	0.87	N.S.
Limb x S.W.G.	3878.9	15	258.6		
Time x Limb	115.2	1	115.2	4.11	N.S
Group x Time x Limb	36.7	1	36.7	1.31	N.S.
Time x Limb x S.W.G.	420.4	15	28.0		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(iii) c) The single most powerful (N.m) contraction generated in the isokinetic single- knee extension fatigue test

Source	SS	df	MS	F	p
Group[a]	1080.9	1	1080.9	0.23	N.S.
Subj. W. Groups	70054.3	15	4670.3		
Time	2160.9	1	2160.9	7.70	<0.05
Group x Time	29.6	1	29.6	0.11	N.S.
Time x S.W.G.	4208.4	15	280.6		
Limb[b]	6.2	1	6.2	0.02	N.S
Group x Limb	82.9	1	82.9	0.20	N.S.
Limb x S.W.G.	6147.5	15	409.8		
Time x Limb	158.8	1	158.8	2.11	N.S.
Group x Time x Limb	77.5	1	77.5	1.03	N.S.
Time x Limb x S.W.G.	1127.9	15	75.2		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes right and left legs.

(iv) a) Maximum power output in a progressive incremental cycle ergometer exercise test

Source	SS	df	MS	F	p
Group[a]	222.2	1	222.2	0.003	N.S.
Subj. W. Groups	1084500.0	16	67781.3		
Kpm/Min.	68053.3	1	68053.3	15.56	<0.01
Group x Kpm/Min.	34724.5	1	34724.5	7.94	<0.05
Kpm/Min. x S.W.G.	70000.0	16	4375.0		

[a] Includes eight Aer and ten AerWt subjects.

(iv) b) Maximum power output in a progressive incremental cycle ergometer test expressed as percent predicted for a healthy control population

Source	SS	df	MS	F	p
Group[a]	5.4	1	5.4	0.03	N.S.
Subj. W. Groups	3447.6	16	215.5		
Percent. Pred.	493.4	1	493.4	16.68	<0.01
Group x Percent. Pred.	217.8	1	217.8	7.36	<0.05
Percent. Pred. x S.W.G.	473.2	16	29.6		

[a] Includes eight Aer and ten AerWt subjects.

(v) a) Submaximal endurance time in seconds to a Borg scale leg effort rating of 4 at 80% of initial Wmax

Source	SS	df	MS	F	p
Group[a]	161939.3	1	161939.3	1.74	N.S.
Subj. W. Groups	1399744.6	15	93316.3		
Time	296534.6	1	296534.6	9.35	<0.01
Group x Time	170868.7	1	170868.7	5.39	<0.05
Time x S.W.G.	475793.5	15	31719.6		

[a] Includes seven Aer and ten AerWt subjects.

(v) b) Submaximal endurance time to a Borg scale leg effort rating of 7 at 80% of initial Wmax

Source	SS	df	MS	F	p
Group[a]	317590.4	1	317590.4	1.4	N.S.
Subj. W. Groups	3378521.9	15	225234.8		
Time	883941.9	1	883941.9	7.06	<0.05
Group x Time	554475.2	1	554475.2	4.63	<0.05
Time x S.W.G.	1877865.9	15	125191.1		

[a] Includes seven Aer and ten AerWt subjects.

(vi) a) The time (seconds) to complete each acsent (36 stairs) in the stair climbing exercise

Source	SS	df	MS	F	p
Group[a]	0.11	1	0.1	0.005	N.S.
Subj. W. Groups	353.8	15	23.6		
Time[b]	10.8	2	5.4	2.46	N.S.
Group x Time	1.9	2	0.9	0.43	N.S
Time x S.W.G.	66.1	30	2.2		

[a] Includes seven Aer and ten AerWt subjects.

[b] Includes one pre- training and two post- training trials.

(vi) b) The resting heart rate (bpm) prior to, and exercise heart rate (bpm) upon completion of, the stair climbing exercise

Source	SS	df	MS	F	p
Group[a]	381.3	1	381.3	0.62	N.S.
Subj. W. Groups	9222.8	15	614.9		
Time[b]	3.9	2	1.9	0.03	N.S.
Group x Time	134.0	2	67.0	1.07	N.S.
Time x S.W.G.	1873.4	30	62.4		
Activity[c]	19047.9	1	19047.9	393.96	<0.01
Group x Activity	14.5	1	14.5	0.30	N.S.
Activity x S.W.G.	725.3	15	48.4		
Time x Activity	25.4	2	12.7	0.61	N.S.
Group x Time x Act.	91.6	2	45.8	2.21	N.S.
Time x Act. x S.W.G.	620.6	30	20.7		

[a] Includes seven Aer and AerWt subjects.

[b] Includes one pre- training and two post- training trials.

[c] Includes heart rate at rest and immediately following each ascent.