A FITNESS APPRAISAL OF CHAMPION OARSMEN, INCLUDING ANALYSIS OF MAXIMUM OXYGEN CONSUMPTION, ELECTROCARDIOGRAM COMPLEXES AND THE BRACHIAL PULSE WAVE AND ITS TIME DERIVATIVES

by

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ABSTRACT

The study had three purposes; first, to appraise the cardiovascular fitness of six world class oarsmen by analysis of their oxygen consumption, heart rate, dynamics of arterial blood flow and various parameters measured from the electrocardiogram; secondly, to explore relatively new techniques for studying and measuring the externally recorded brachial pulse wave, its first derivative and the phase plane relationship of this derivative with the original pulse wave; and lastly, to determine the effectiveness of a conditioning programme designed to improve the cardiovascular efficiency, muscular endurance, strength and stamina of these oarsmen.

The experimental design allowed each of the six subjects to be tested twice before and twice after an eight week conditioning programme. Each test battery included a maximum bicycle ergometer ride to exhaustion, a submaximal five minute step test, a mile run for time, dynamometer strength tests and a muscular endurance test. The conditioning programme consisted of circuit training, strength training and endurance running, there being five workouts in each seven day period.

Patterns and values of oxygen consumption, T-wave $\leq$ RS and heart rate change during rest, exercise and recovery from exercise and patterns of change and qualitative and quantitative appraisal of the brachial pulse wave, its first derivative and the phase plane loop during rest and recovery from exercise have been described.

The results indicate that though muscular endurance, strength and work capacity increased with training, significant differences were not

noted between pre- and post-training values in 39 of 42 cardiovascular variables tested by the t-test. Possible reasons for these facts were suggested. The data did indicate that the maximum oxygen consumption of these oarsmen was greater than that reported for the general public but less than that reported for world class cross country skiers and distance runners. The pattern of change of both the pulse wave and T-wave amplitude during recovery from exercise suggested the possible importance of these variables as indicators of degrees of fitness.

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INTRODUCTION TO THE PROBLEM

Statement of the Problem

The work capacity of champion endurance athletes is of particular interest to applied physiologists and medical scientists studying the cardiovascular and pulmonary factors which influence the accomplishment of specific work tasks. Endurance competition at the highest level is characterized by an athlete's ability to maintain extremely high work rates. This activity requires highly efficient gas exchange, circulatory and metabolic processes. A study of the work capacity of world class oarsmen utilizing established cardiovascular parameters might allow the physiological responses of these athletes to be studied and compared with the work capacity of other champion athletes and non-athletes reported by other investigators.

It is not always easy in studies concerning human performance capacity to investigate internally the multitude of physiological reactions that represent hemodynamic responses to work tasks. External measurement of the brachial pulse wave and its time derivatives, however, have permitted some insight into the role and efficiency of the heart and blood vessels to pump and convey blood to the working tissue. The development of highly sensitive pulse wave transducers, amplifying, differentiating and display equipment now allows high accuracy in the measurement of arterial pulse wave amplitude changes. It is the second purpose of this study to present and explore relatively new techniques for studying externally recorded brachial pulse pressure waves, including the first

derivative of the pulse wave and the phase plane relationship of this derivative with the original pulse wave.

A conditioning programme designed to improve cardiovascular endurance (stamina), strength and muscular endurance of these oarsmen is included in the study. Thus, some stimulus to making real changes in improving physical condition throughout the period of study is provided and the discriminatory power of the test parameters between the initial and final testing will be better evaluated.

Justification of the Study

A scientific study of the performance capacity of Olympic and international calibre oarsmen can provide valuable information regarding the efficiency of their pulmonary, cardiovascular, metabolic and hemodynamic responses to the stress of maximal and submaximal work tasks. These responses can be compared to other data from athletes and non-athletes with the ultimate purpose of differentiating physiological responses between these two groups.

Any new methods of measurement, whether they arise from the development of improved techniques or the determination of new parameters, must be considered as attempts to increase the accuracy and volume of knowledge of a specific area. The techniques used in this study for investigating externally recorded pulse pressure waves and their time derivatives are relatively modern and might be expected to contribute to knowledge concerning the dynamics of the pulse pressure wave and its role as an indicator of fitness.

Finally, physical conditioning programmes for world class oarsmen

have improved considerably in the past five years primarily because training now includes off-water conditioning during the winter months to augment the summer on-water training. Acceptable off-water training methods have been derived from athletes and trainers in other endurance sports who have, in most part, established their conditioning programmes from empirical observations. The literature contains little information regarding conditioning programmes for international competition. The off-water conditioning programme included in this study is an attempt to effectively condition the oarsmen as well as allow an increase in the number of observations made on the work capacity of these oarsmen.

Delimitations of the Study

The six subjects studied were international oarsmen at the university. A test battery was devised and administered four times to the subjects. The study period, lasting for ten weeks, consisted of two pre-testings performed a week apart, an eight week conditioning programme, and two post-testings performed a week apart. The test battery primarily consisted of a bicycle ergometer ride to exhaustion (maximal test) and a five minute step test (submaximal test). The parameters studied were oxygen consumption, heart rate and electrocardiogram complexes, brachial pulse wave analysis, work capacity, static and dynamic strength, and stamina as reflected in a mile run. The conditioning programme was designed to improve static and dynamic strength and stamina.

Limitations of the Study

1. Only six subjects were studied.
2. There was no control group and thus no direct comparisons

could be made. The study was limited to determining certain physiological characteristics of these oarsmen and then comparing these characteristics with other data in other literature.

3. The oarsmen commencing the study were very fit and positive changes in their fitness resulting from the conditioning programme might not easily be determined.

4. There was no random selection of the subjects in that this study involved a select group of athletes.

Definitions

Basic Fitness Factors - The four factors outlined in this study are four of nine isolated by factor analysis by Fleishman (1). The four factors are defined below:

Static Strength Factor - The maximum force a subject can exert even for a brief period when the force is exerted continuously up to this maximum. In contrast to other strength factors, this is the force which can be exerted against external objects rather than in supporting or propelling the body's own weight.

Explosive Strength Factor - The ability to expend a maximum of energy in one or a series of explosive acts. This factor is distinguished from other strength factors in requiring mobilization of energy for a burst of effort rather than continuous strain, stress or repeated exertion of muscles.

Dynamic Strength Factor - The ability to exert muscular force repeatedly or continuously over a period of time. It represents muscular endurance and emphasizes the resistance of the muscle to fatigue. The common emphasis of tests measuring this factor is on the power

of the muscles to propel, support or move the body repeatedly or to support it for prolonged periods.

Stamina (Cardiovascular Endurance) Factor - The capacity to continue maximum effort requiring prolonged exertion over a period of time. Stamina depends on the efficiency of the heart and vascular system.

Circuit Training - This refers to the circuit regimen and procedures designed for this programme unless otherwise stipulated.

Maximum Oxygen Consumption - In the present study, maximum oxygen intake refers to the average rate of oxygen intake calculated over the last three minutes of an exhaustive ride on a bicycle ergometer, the ride lasting at least ten minutes and up to twenty minutes. Maximum oxygen consumption is an indicator of physical fitness and reflects an individual's maximum efficiency in accepting, transporting and utilizing oxygen during aerobic metabolic processes.

Muscular Strength - This refers to both static and explosive strength.

Physical Work Capacity (Performance Capacity) - Physical work capacity is the maximum quantity of work per unit time an individual is physically capable of performing when attempting an exhausting work task. The quantity of work accomplished per unit time is an indicator of the individual's physical fitness.

Pressure Pulse - The whole pressure curve obtained when recording peripheral arterial deformation is designated the pressure pulse.

World Class Oarsmen - The oarsmen in this study have rowed in some or all of the following competitions: Copenhagen International Regatta 1965, Olympic Games 1964, Pan American Games 1963, British Empire Games 1962, World Championships 1962. Each oarsman has won a first place medal in one of the first three regattas mentioned.

REFERENCES

1. Fleishman, E.A., The Structure and Measurement of Physical Fitness, Prentice-Hall Inc., N.J., 1964, pp. 130-131.

CHAPTER II

RELATED LITERATURE

A. OXYGEN CONSUMPTION ANALYSIS

A major portion of the present study concerns the determination of the working capacity and cardiovascular efficiency of world class endurance athletes (oarsmen). Endurance athletes are characterized by their ability to perform a high rate of work for long periods of time. The quantity of work one can perform until exhaustion occurs indirectly indicates the efficiency of the cardiovascular and metabolic processes in performing the work but does not indicate which factors prove limiting to the work. The quantity of energy actually expended while working to exhaustion can be measured directly by the determination of the oxygen uptake required to perform the work task. The aerobic capacity and efficiency of cardiovascular function is determined by the maximum rate of oxygen consumption an individual can achieve. It has been established (1) that the more oxygen the cardiovascular system can accept, transport and release to the working tissue, the greater the aerobic metabolism in this tissue and ultimately, the greater is the ability of the tissue to perform the work task. The amount of oxygen consumed in performing work does not itself measure the degree of exhaustion caused by the work. The actual oxygen intake must be judged with regard to the amount of working muscle. (2).

Maximum Oxygen Intake as an Indicator of Fitness

Many investigators (3,4,5,) feel that the maximum oxygen intake

test indicates both the ability of the heart to propel blood mechanically and the ability of the tissues to extract oxygen from the blood perfusing them. Thus, maximum oxygen intake has often been accepted as an index of cardiovascular function. Balke and Ware (6), however, do not believe oxygen consumption is an accurate evaluator of work capacity, because of the wide variation of individual values.

Factors Influencing Maximal Oxygen Intake

The Fick equation (7) indicates those cardiovascular factors that determine maximum oxygen intake:

Oxygen Uptake = Heart Rate (b/min) x Stroke Volume (ml/b) x A-V Oxygen Difference (vol %)

if ventilatory or diffusive (pulmonary) factors are not involved. It appears (8) that these are not limiting and that during heavy exercise the maintenance of constant arterial and venous oxygen tensions is a common occurrence.

Heart rate and stroke volume together determine the quantity of blood per unit time (cardiac output) ejected from the heart. The greater the cardiac output, the greater is the quantity of oxygen that can be transported to the working tissue. It appears (9) that during light work and under normal conditions, both the stroke volume and heart rate contribution to cardiac output increase. At work loads over 40% aerobic capacity the stroke volume becomes limiting and the heart rate becomes almost the sole contributor to cardiac output. At 40% aerobic capacity the heart rate is about 120 b/min. Once the maximum stroke volume is reached, it apparently remains constant during heavy work. Individuals with high work capacity are usually distinguishable from those with low

work capacity by their larger stroke volumes (10).

The present study is not primarily concerned with the temporal appearance of limiting cardiovascular factors, but with the influence these factors have in determining the maximum oxygen intake. Theoretically, the degree to which the A-V oxygen difference can expand is, like cardiac output, a determining factor. The greater the oxygen difference between arterial and mixed venous blood, the greater is the oxygen available for aerobic metabolism. The magnitude of the oxygen gradient is mostly influenced by encroachment on the mixed venous oxygen content (11). This is possible by two mechanisms - the extent to which blood perfusing working tissue can surrender oxygen, and the shunting of blood from inactive areas.

The maximum oxygen intake test should not demand any unusual type of skill for successful performance. However, the speed of effort and its relation to skill must be considered. Repeated efforts on a bicycle ergometer might lead to increases in skill and therefore a decrease in the maximum rate of oxygen consumption for the same task (12). Additionally, if the given task requires skill to perform, the person with low fitness may possibly, by practice, accomplish it more easily than the unskilled person with high fitness.

It is important that the work be of sufficient intensity so as to elicit maximum oxygen consumption yet not so intensive as to make motivation play a dominant part. Many investigators (13,14,15) feel that exhaustion should occur within three to five minutes after initiation of the exercise.

If the cardiovascular system is to be placed under considerable

stress, the work must involve large groups of muscle so that local muscular fatigue is not a limiting factor. The oxygen intake is influenced by the mass of muscle used. Taylor (16) found that the addition of a hand ergometer work task to a treadmill performance increased the maximum rate of consumption by 200 cc. Saltin and Astrand (17) found that inclusion of both arms and legs in a work task showed no increase in maximum oxygen consumption and heart rate above legs only, but work could be tolerated for up to twice as long as when leg work alone was utilized. Taylor (18) states that at high rates of respiration, the respiratory muscles use a measurable amount of oxygen, perhaps as much as 1100 cc/min. Increase in muscular strength by training might result in a decrease in the maximum oxygen intake for a given task. Stronger muscles use less fibers to perform a given task (19) and perhaps use less oxygen.

Body size and composition are important considerations when measuring the rate of oxygen intake. Buskirk and Taylor (20) indicate that "....excess fat per se does not have any important influence on the capacity of the cardiovascular system to deliver oxygen to the muscles under maximum performance conditions". The extra load carried by the obese man "....does not produce extra stress on the cardiovascular-respiratory system during exhaustive work but makes accomplishment of a specific work task more difficult. The excess fat does not increase the oxygen cost and therefore the load in submaximal work". Oxygen consumption is best expressed as millilitres oxygen per kilogram body mass per minute (21).

In addition, it appears that control of environment, length and

intensity of warm-up, motivation, degree of fitness and health, and physiological status of the body systems are all considerations when determining maximum oxygen intake (22).

Criteria That Define Maximum Oxygen Intake

When attempting to determine reliably the maximum oxygen intake it is necessary to establish criteria to indicate when maximum intake occurs. The actual value reached for a given individual apparently depends on the nature of the physical activity. It is therefore maximal for a given set of conditions.

The criterion most commonly used is the oxygen plateau observed when the curve indicating the relationship of oxygen intake (ordinate) against work load (abscissa) becomes asymptotic (23). Astrand (24) uses both the oxygen plateau and the blood lactate level as criteria, feeling the latter offers a valuable control for the degree of exhaustion. Taylor (25) feels the oxygen plateau is a valid criterion if the intensity of work exhausts the subject in five minutes. Wyndham et al. (26) do not believe an oxygen plateau exists in reality and state: "High work rates were not studied by Taylor and.... they missed the slow approach of oxygen intake to the asymptote. Failure to take this into account leads to underestimation of oxygen". They feel the curve approaches the asymptotic value only slowly.

Relationships and Values of Oxygen Intake

At low work rates there appears to be a linear relationship between both oxygen intake and heart rate plots against work rate (27). At high work rates (about 970 - 1100 kgm/min) the curves tend towards an

asymptote (28). The oxygen intake curve is slower in approaching its asymptote than is the heart rate curve. Two reasons have been suggested for this. It is possible that psychological factors limit the work output rather than energy output factors. The lactic acid concentration of the blood provides no information on this point because a high level of lactic acid only indicates that an aerobic metabolism is proceeding rapidly (29). There is considerable difference in the time individuals will work with such lactic acid concentration. Secondly, in bicycle ergometry, the individual mainly uses lower extremity and lower trunk muscles at low levels of work. Often at high levels of work there is inclusion of shoulder girdle and trunk muscles which act as fixators when an individual is straining to maintain the pace of work. With an increase in working tissue, there is generally an increase in oxygen intake.

Previously it was indicated that maximum oxygen intake is dependent on several factors, one being the type of work task utilized. This study includes the determination of maximum aerobic capacity of world class oarsmen since there is reason to believe they might be capable of achieving very high rates of oxygen consumption. Therefore, for comparison purposes, the review of literature has included values of maximum oxygen consumption obtained on various athletes performing bicycle, treadmill, and other work tasks.

Oxygen Intake in Normal and Athletic Males

Mitchell (30) studying normal males aged 20-29 performing on a treadmill obtained a mean maximum oxygen intake value of 3.37 l/min or 44.7 ml/kg/min. Buskirk and Taylor (31) report a mean value of

3.44 ∓ 0.46 l/min for normal males and 3.95 ∓ 0.43 l/min for well-trained males. Swedish athletes aged 20-29 studied by Astrand (32) had a mean value of 4.15 ∓ 0.36 l/min. Slonim, Gillespie and Harold (33) report a mean value of 4.05 ∓ 0.39 l/min with a range of 3.22-5.17 l/min for a group of naval cadets aged 18-20. Saltin (34) indicates that of the many individual values he obtained, the highest intakes were 4.23 l/min for one group just cycling, and for another group, 4.36 l/min for cycling and 4.48 l/min for skiing. Robinson, Edwards and Dill (35) report very high maximal intake values for former mile world record holder Don Lash during treadmill exercise. During the last three minutes of a maximal task he had intakes of 4.96, 5.08 and 5.1 l/min respectively. He elevated his resting metabolic rate 2.4 times. Dill et al. attribute his high rate of intake to his extremely high cardiac output. His blood was found to be normal in oxygen carrying capacity. Kipping (36) found values of oxygen uptake in excess of 5 l/min. Christianson and Hoberg (37) have obtained an oxygen consumption value of 5.24 l/min on Olympic Nordic ski champion Sixten Jernberg. Astrand (38) when measuring a cross section of the population determined that up to 25 years of age, the average of the highest recorded oxygen intakes ranged from 47-53 ml/kg/min. For a group of healthy, well-trained soldiers 20 years old, Andersen (39) found the maximum oxygen intake to be 53.2 ml/kg/min. Astrand (40) found world class athletes had remarkably higher oxygen intake values than those for normal males the same age. The world class athletes had consumption values of 67 or more ml/kg/min against an average of 58.6 ml/kg/min for students the same age. Astrand presents the following table:

TABLE I

HEART RATE AND MAXIMUM OXYGEN INTAKE OF WORLD CLASS

1500 METER RUNNERS AND CROSS COUNTRY SKIERS
(AFTER ASTRAND)

Runner	Heart Rate b/min	Maximum l/min	Oxygen Intake ml/kg/min
Erikson	184	5.29	68.1
Landy	195	5.04	76.6
Skier			
Jernberg	179	5.88	81.7
Larsson, L.	182	5.49	81.3
Larsson, P.E.	190	5.38	80.3
Samuelson	182	5.34	78.5

Astrand (41) studying subjects pedalling a bicycle ergometer obtained the following values:

Max. O_2 intake	Heart Rate
4.19 l/min	192 b/min
4.49	192
4.24	190
5.30	185
4.15	194

Astrand (42) studying six male Swedish cross country skiers found the average oxygen intake when skiing was 5.02 l/min compared to 4.92 l/min when cycling.

B. HEART RATE AND ELECTROCARDIOGRAM ANALYSIS

Heart Rate as an Indicator of Fitness

The heart rate is an established parameter utilized by work physiologists to determine the amount of strain an individual is experiencing. Le Blanc (43) feels that the main factors involved in muscular activity are those related to both the oxygen supply of the muscles and the dissipation of the heat produced, and that these factors are dependent on how the circulatory system adapts itself to the body requirement. Balke and Ware (44) consider the heart rate at any given load to be the best measure of physiologic function. Consalazio (45) states that of all the measures of physical efficiency the pulse rate during severe exercise seems to be the most reliable. Many investigators (46,47) feel that the resting heart rate is not an important measure of physical fitness but that the recovery heart rate is a better indicator. Robinson, Edwards and Dill (48) found that after exhaustive exercise, heart rate recovery was faster in trained than in untrained individuals and attained a lower final level. Astrand (49) feels the recovery heart rate varies from one individual to another if their physical condition is roughly the same. He feels recovery values can be used if one wishes to compare an individual's pre and post-training states, but not when making inter-individual comparisons.

The maximum heart rate an individual can achieve has been the subject of much research. Robinson _et al._ (50) found that for trained college men, the mean maximum rate was 189 b/min and for untrained men 190 b/min, but the trained were performing greater work loads. Astrand (51) also feels that the heart rate is the same for trained and untrained when

performing maximal work but training increases an individual's aerobic capacity as well as his capacity to increase his oxygen debt. Astrand (52) reports the mean maximal heart rate obtained on normal healthy young men was 195 (σ=10). Brouha (53) indicates a mean maximal heart rate of 193 obtained from 176 college males during exhausting treadmill exercise. Lewis and Morton (54) report a mean maximal value of 195 for well-trained subjects aged 18-30 during exhausting work.

Astrand (55) found that four skiers could maintain a high constant speed for 120-160 minutes with a pulse rate of 170-180. Slonim, Gillespie and Harold (56) found the heart rate at peak oxygen uptake was 188 ∓ 7.9 b/min with a range from 174-204 b/min. Similar values can be observed from the tables of Astrand shown above on world class 1500 meter runners and cross country skiers.

The Electrocardiogram as an Indicator of Fitness

The electrocardiogram (ECG) is a temporal record of the electromotive forces which originate during the activation of the myocardium. From the record, some interpretation of the physiologic events accompanying this electrical activity may perhaps be made. The ECG is not, however, an indicator of mechanical heart function. This can only be determined by the analysis of stroke volumes and the varying pressures developed during the heart cycle. Interpretation of the electrocardiogram is based on three fundamental elements: the theory of impulse derivation, the form of the individual action potential and the spread of myocardial activation. The shape of various ECG deflections is altered by many different factors including: position of the recording electrodes on the body surface, orientation of the heart within the thorax, the thickness of the walls of the heart, the course of excitation through the myocardium, the rate of

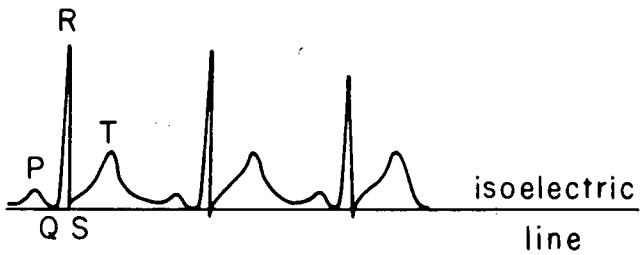
depolarization and repolarization and the extent of polarization and depolarization (57, 58). Cureton (59) lists some 47 conditions other than disease which affect the ECG including exercise, obesity, hyperthyroidism, acidosis, alkalosis, hypoglycemia and fear.

Figure 1 shows a labelled ECG tracing. The tracing may be composed of P, Q, R, S, and T deflections or waves.

The T-wave represents ventricular repolarization. Cureton (60) indicates that the amplitude of the T-wave increases after moderate exercise and is reduced after marathon running and during oxygen deficiency. Hoogerwerf (61), after studying 260 Olympic athletes, found that the T-wave became higher with exercise, but with all-out work became very small. Cooper et al. (62) found an increase in height of the T-wave of trained college oarsmen after rowing a mile while untrained subjects showed lower T-waves. Carlisle (63) studying over 100 Australian athletes states that severe physical effort causes, in some subjects, a progressive flattening of the T-wave. The changes in the T-wave appear closely related to the amount of training. Hunt (64) after studying 20 swimmers at the peak of their training found that all showed marked loss in voltage when tested immediately after a hard race. In ten cases, inversion occurred and only one of these recovered by 30 minutes. Five showed peaked T-waves at 3 minutes post-exercise then decrease after this to below resting level. The cause of T-wave depression during severe training is uncertain.

The QRS complex denotes ventricular depolarization. The amplitude and duration of the QRS largely depends on the bulk of ventricular muscle tissue activated. The Q wave if present, is a downward deflection indicating the onset of ventricular contraction. The time interval Q-T

Figure 1 The P and T waves and the Q,R,S points of the ECG taken during rest, the electrodes being placed on the sternum and fifth intercostal space sublateral of the heart. The T wave amplitude is the distance between the highest point on the T wave and the base line. The RS amplitude is the distance between the R and S points.



TYPICAL ELECTROCARDIOGRAM TRACING

represents ventricular action and during the S-T interval the ventricle is contracting and repolarization will occur. Cureton (65) states the R-wave is positively correlated with the brachial pulse wave, endurance running time on a treadmill and heart size. Hoogerwerf (66) found that the QRS complex decreases to about one-half size after exercise. Wolf (67) found in untrained subjects the S-wave increased and the R-wave decreased following exercise. With training, the R- and S-waves increased after exercise. Rose and Dunn (68) state that so many factors affect the QRS amplitudes that the measurement, per se, has little value in identifying the state of training of a given individual in the absence of a previous record for purposes of comparison.

C. BRACHIAL PULSE WAVE ANALYSIS

Arterial pulse waves have been a reliable source of information concerning the cardiovascular system. Physiologists and more recently physical educationists have analyzed pulse waves to study the characteristics of the peripheral blood vessels, blood flow and the ejection dynamics of the heart (69-74).

Ideally, arterial pulse pressure should be measured intra-arterially by placing pressure transducers directly in the artery lumen. However, the trauma and techniques involved with intra-arterial puncture makes this practice unacceptable to many investigators. Indirect methods for measuring peripheral pulse pressure have been developed to study externally the pressure deformation of a single artery (75,76).

The assumption made when measuring the pulse pressure externally is that the changes in pressure, measured externally, are a linear

function of the internal pressure changes in the artery. Hyman (77) indicates that the validity of this assumption depends upon the individual being measured, the assumption probably being invalid under conditions of sclerosis and other modifications of arterial distensibility. Dontas (78) in a study comparing simultaneously recorded intra-arterial and extra-arterial pulse pressures of the same artery found that the extra-arterial pulses from young males resembled intra-arterial pulse contours if the cuff pressure was kept slightly below diastolic levels (60 mm. Hg.). Starr and Ogawa (79) have outlined the characteristics of wave distortion that might occur if the pressure transducer was not attached properly.

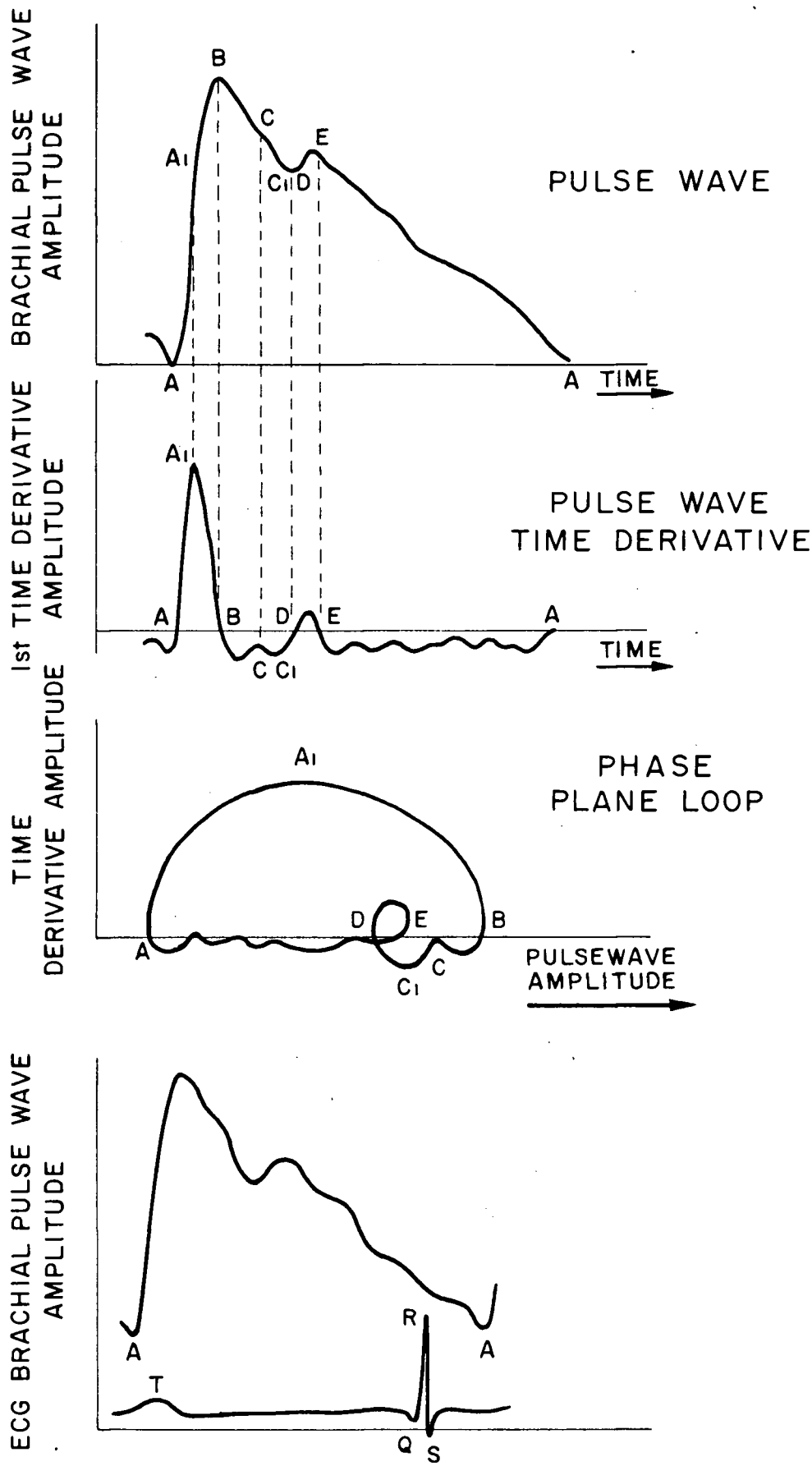
With the advent of sensitive external pressure transducers, appropriate amplifying and differentiating circuits and recorders (80), external recordings of the peripheral pulse have proved valuable indicators of the state of the peripheral circulation to clinicians and are now being studied by physical educationists to determine if pulse waves are useful indicators of fitness and the stresses that arise from exercise.

Description of the Peripheral Pulse Wave

The characteristics of normal (Figure 2) and abnormal pulse waves have been described (81-84). Hyman (85) has described the characteristics of abnormal waves indicating that during the presence of an arterial obstruction the curve is characterized by a low amplitude, a slowly rising anacrotic limb, rounding of the apex, diminution or absence of a dicrotic notch, a delayed crest time and low systolic and diastolic blood pressure. In contrast, the characteristics of waves

Figure 2 The Brachial Pulse Wave, First Time Derivative, Phase Plane Loop and Electrocardiogram, during rest. The percussion wave forms the peak pulse.

A-A = Heart Cycle Time, A = Initiation of Upstroke, A-B = Brachial Upstroke Time, B = Primary Peak (Point of Maximum Pressure), C = Tidal Wave, B-D = Reduced Ejection Period, D-A = Diastolic Filling Time, D = Dicrotic Notch, E = Dicrotic Wave, $A_1 = +\dot{p}$ (Maximum rate of change of positive pressure), $C_1 = -\dot{p}$ (Maximum rate of change of negative pressure).


BRACHIAL PULSE WAVE AMPLITUDE
B
C
E
A1
C1
D
A
A
TIME
PULSE WAVE
1st TIME DERIVATIVE AMPLITUDE
A1
A
B
D
E
A
C
C1
TIME
PULSE WAVE
TIME DERIVATIVE
TIME DERIVATIVE AMPLITUDE
A1
D
E
B
A
C
C1
PULSEWAVE AMPLITUDE
PHASE
PLANE LOOP
ECG BRACHIAL PULSE WAVE AMPLITUDE
R
A
A
T
Q
S

indicating a relaxed vessel wall include volume curves of high amplitude, often a large dicrotic notch with a normal rate of rise of the anacrotic limb and an arterial pulse pressure that is normal or low.

Exercise affects the shape of the pulse wave. As the cardiac output increases the externally recorded volume curves appear normal in form, but have a high amplitude, the arterial pulse pressure is high and the ejection time decreases.

The shape of the pulse has been explained in terms of wave mechanics. McDonald (86) discussing the dynamics of the peripheral pulse wave, states that the high frequency components, as indicated by the incisura (which is synchronous with the closure of the aortic valves) have been damped out while the lower frequency components have been exaggerated. The presence of the dicrotic notch is assumed to be partly due to wave reflection from the periphery and the interval between the initial peak and the dicrotic peak has been taken as a measure of resonant frequency.

The peripheral pulse wave can indicate systolic and diastolic time intervals. Systole has been described as consisting of two phases - an isometric phase of rising tension and a period of ejection described as auxotonic (87). The isometric period is subdivided into pre-isometric and isometric phases. The ejection period can be subdivided into a period of maximum ejection extending from the initiation of steep pressure increase until the upstroke summit of the pressure curve and a period of reduced or absent ejection extending from the upstroke summit to the incisura.

Wiggers (88) has described diastole as composed of four periods.

The early fall in ventricular pressure constitutes two diastolic phases - a proto-diastolic phase extending the duration of the incisura of the arterial pressure curve, and a second phase of isometric relaxation extending from the closure of the semilunar valves and the opening of the atrio-ventricular valves. A third period of rapid filling of the ventricle and a fourth period of diastolic or reduced blood flow to the ventricle. Identification of these four phases of diastole cannot be made from the peripheral pulse wave tracings.

The measurement of the ejection phase of systole - i.e. both the period of initial ejection (brachial upstroke time A-B) and the period of reduced or absent ejection (end of upstroke-incisura B-D) is made in the study (Figure 2). The diastolic filling time is measured from D to A and includes the four diastolic phases as well as the isometric phase of systole.

The interval Q-upstroke, measured from the simultaneous records of the pulse wave and the ECG, includes an electromechanical lag, an isovolemic contraction period and the pulse transmission period. Harrison et al. (89) indicate that with advancing age, the isometric relaxation period decreases, the pulse transmission time declines, the duration of ejection as a percentage of heart rate does not change and the Q-carotid upstroke interval is slightly reduced.

The First Derivative of the Pulse Wave Contour

It is possible by means of differentiating circuits to measure the rate of change of volume in the artery at any one specific time. This derivative curve is highly sensitive and tends to highlight small changes in the primary wave which may not be visible on first inspection. The

derivative emphasizes high frequency phenomena of the primary wave such as angles, notches and slurs (90). In contrast, low frequency phenomena such as wandering of the base line with respiration are greatly reduced or eliminated. Differentiating circuits have been described by many investigators (91,92,93).

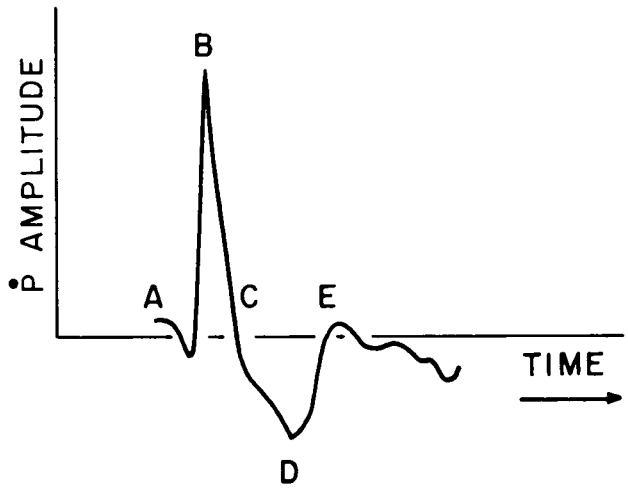
Starr (94) has described the normal first derivative wave as follows (Figure 3):

> "At the arrival of the pulse, there is a sharp take-off angle at A occasionally preceded by a small, very brief downward deflection. The AB segment is smooth and rises sharply to a single peak at B. The descending BC segment is not so steep as the primary ascent and is usually concave upward. The principal downward peak at D is sharp. The distance of D below the base line is approximately one-third that of B above it. After D there is usually a small upward peak that may or may not reach the base line at E, followed by a descent after which the record generally approaches the base line to reach it just before the arrival of the next pulse."

Investigators have identified two typical pulse wave forms from normal individuals and the two waves can be readily distinguished by inspection of their first derivatives (95,96). The first derivative has facilitated recognition of abnormal records. In general, abnormal records show notches and doubled waves. The principal upward wave seems to be broader and the take-off angle is sometimes more rounded than in normal records (97).

The maximum velocity of the ascending pulse wave (ht. of B) and the time intervals AB, BC, CD, and AC (Figure 3) for both normal and abnormal waves, have been measured from the first derivative by various investigators. These time intervals have been expressed in seconds or as a percentage of pulse time in order to correct for pulse rate. The time intervals are directly influenced by the position and size of the

Figure 3 The first time derivative of the Brachial Pulse Wave, after Starr.


$\dot{P}$ AMPLITUDE
B
A
C
E
D
TIME

inflections represented in the pulse wave which in turn seems to depend on the condition of the cardiovascular system.

Starr and Ogawa (98) studied healthy subjects to obtain normal standards for contour, amplitude of the main deflection and duration of the main waves on the base line. As age advanced, the main wave of the pulse derivative diminished in amplitude and became broader on the base line even though health commensurate with one's age was retained. Patients with cardiac disease showed abnormal pulse derivative contours. These changes from normal apparently indicated myocardial weakening as one grew older. Abnormalities of wave duration were found in a small number of patients. Dontas (99) utilized the pulse wave and its first derivative to estimate the degree of central arterial distensibility by determining the ratio of the height at the point of the first anacrotic slowing to the total pulse height in per cent. This was found to be constant from day to day in middle-aged patients and similarly constant daily values were found for peak time and relative peak time. Banister et al. (100) indicate the effect of training is to shorten the systolic upstroke time and to maintain a long diastolic filling period even during elevation of the heart rate during exercise. Weissler (101) in studying the relationship between ejection time, stroke volume and heart rate determined that in normal persons ejection time varied inversely with heart rate and directly with stroke volume. As stroke volume increased the mean rate of ejection (ml/sec) increased.

The Phase Plane Loop

The phase plane relationship between the rate of change of pulse amplitude (first derivative) and rising pulse amplitude can be obtained

and displayed by the differentiating, amplifying and display equipment outlined in this study. If the rate of change of amplitude as ordinate is plotted against the pulse amplitude as abscissa, the result is the formation of a loop. Brown, Banister and Dower (102) have described and illustrated the formation and nature of the phase plane loop. For untrained subjects, the maximum rate of change of positive amplitude have higher values and occur later in the anacrotic limb of the pulse amplitude waves. The maximum rate of change of negative amplitude have lower values and occur later along the catacrotic slopes of the pulse pressure waves.

D. THE EFFECT OF TRAINING ON WORK CAPACITY, CARDIOVASCULAR AND MUSCULAR FITNESS

Training to improve one's physical fitness results in the following: light, moderate and exhaustive work can be performed more efficiently with less displacement of physiological equilibria; at very high rates of work, the physiological equilibria can be displaced further for a longer period of time; ventilation during work is more efficient and a greater maximal ventilation can be achieved; a greater mechanical efficiency occurs and is reflected in a lower oxygen consumption for a given amount of work; a greater maximum oxygen consumption can be attained; systolic blood pressure during work is usually lower; the physiological processes return more rapidly to normal after exhausting exercise (103).

With training, the heart is able to circulate more blood while beating less frequently. Contraction of the heart becomes more powerful, it empties itself more completely at systole and stroke volume and cardiac output are increased. There is a longer diastole resulting in

greater blood volumes in the heart at the onset of systole, faster systole, greater minute volume and increased cardiac muscular endurance because of its own improved cardiac blood flow and improved cardiac-neural control. Strong cardiac training tends to increase the size and flexibility of the blood vessels and the degree of capillarization in the working tissue (104).

Endurance training involves both muscular endurance and cardio-vascular-respiratory efficiency. Applied to the muscles, endurance training tends to improve the speed of contraction and the number of contractions able to be made (105). It appears (106) that the endurance of a muscle is improved by increasing the degree of capillarization in the muscle. The inference is that the reactants for aerobic metabolism will be in better supply in the 'conditioned' muscle and the wastes will be eliminated more efficiently. Strength training, differentiated from endurance training, is characterized by an increase of the myofibril diameter (107) and does not infer reliance on the cardiovascular system (108). The gain in static or explosive strength does not always mean a gain in dynamic strength and the final result of training on the muscle varies with the kind of exercise performed, the degree of repetition, speed, duration, and intensity of contraction (109).

REFERENCES

1. Hill, A.V., Lupton, H., "Muscular Exercise, Lactic Acid and the Supply and Utilization of Oxygen", Quart. J. of Medicine, Vol. 16, 1923, pp. 135-171.

2. Astrand, P.O., "Human Physical Fitness with Special Reference to Age and Sex", Physiological Reviews, Vol. 36, 1956, p. 327.

3. Wyndham, C.H., Strydom, N.B., Maritz, J.S., Morrison, J.F., Peter, J., Potgieter, Z., "Maximum Oxygen Intake and Maximum Heart Rate During Strenuous Work", J. Appl. Physiology, Vol. 14, 1959, pp. 927-36.

4. Mitchell, J.H., Sproule, B.J., Chapman, C.B., "The Physiological Meaning of the Maximal Oxygen Uptake Test", J. of Clinical Investigation, Vol. 37, p. 538.

5. Saltin, B., "Aerobic Work Capacity and Circulation at Exercise in Man", Acta Physiol. Scand., Vol. 62, Supp. 230, 1946, p. 37.

6. Balke, B., Ware, C.W., "An Experimental Study of Physical Fitness of Air Force Personnel", U.S. Armed Forces Medical Journal, Vol. 10, June, 1959, pp. 675-88.

7. Saltin, B., op. cit., p. 10.

8. Saltin, B., op. cit., p. 20.

9. Saltin, B., op. cit., p. 38.

10. Christiansen, E.H., "Beiträge zur Physiologie schwerer körperlicher Arbeit. VII. Mitterlung: Über die Brauchbarkeit der Acetylenmethod zur Bestimmung des Herzminuten-volumens währed körperlicher Arbeit: Arbeitsphysiologie, 1932, pp. 479-488.

11. Mitchell, Sproule, Chapman, op. cit., pp. 538-47.

12. Taylor, H.L., Buskirk, E., Henschel, A., "Maximum Oxygen Intake as an Objective Measure of Cardio-Respiratory Performance", J. of Appl. Physiol., Vol. 8, 1955, pp. 73-80.

13. Ibid.

14. Consolazio, F.C., Johnson, R.E., Pecora, L.J., Physiological Measurements of Metabolic Functions in Man, McGraw-Hill Inc., Toronto, 1963, p. 341.

15. Astrand, P.O., Rhyming, I., "A Nomogram for Calculation of Aerobic Capacity (Physical Fitness) from Pulse Rate During Submaximal Work", J. Appl. Physiology, Vol. 7 (2), 1954, pp. 218-21

16. Taylor, Buskirk, Henschel, loc. cit.

17. Astrand, P.O., Saltin, B., "Maximal Oxygen Uptake and Heart Rate in Various Types of Muscular Activity", J. of Appl. Physiol., Vol. 16, 1961, pp. 977-80.

18. Taylor, H.L., "Exercise and Metabolism", Science and Medicine of Exercise and Sports, Harper Bros., New York, 1960, p. 144.

19. Banister, E.W., "Physiological Principles Applied to a New Method of Strength Training", Unpublished, U. of British Columbia, 1966.

20. Buskirk, E., Taylor, H.L., "Maximum Oxygen Uptake and its Relation to Body Composition with Specific Reference to Chronic Physical Activity and Obesity", J. Appl. Physiol., Vol. 11, 1957, p. 72.

21. Astrand, P.O., Rhyming, I., loc. cit.

22. Taylor, Buskirk, Henschel, loc. cit.

23. Wyndham, Maritz, Strydom, Morrison, Peter, Potgieter, loc. cit.

24. Astrand, op. cit., p. 309.

25. Taylor, Buskirk, Henschel, loc. cit.

26. Wyndham, Strydom, Maritz, Morrison, Peter, Potgieter, loc. cit.

27. Mitchell, op. cit., pp. 538-547.

28. Wyndham, Strydom, Maritz, Morrison, Peter, Potgieter, loc. cit.

29. Ibid.

30. Mitchell, loc. cit.

31. Buskirk, Taylor, loc. cit.

32. Astrand, op. cit., p. 309.

33. Slonim, N.B., Gillespie, D.G., Harold, W.H., "Peak Oxygen Uptake of Healthy Young Men as Determined by a Treadmill Method", J. Appl. Physiol., Vol. 10, 1957, p. 401.

34. Saltin, op. cit., p. 15.

35. Robinson, S., Edwards, H.T., Dill, D.B., "New Records in Human Power", Science, Vol. 85, 1937, pp. 409-10.

36. Kipping, H.W., Deutsche med Wehnschr, Vol. 63, 1937, p. 462.

37. Christiansen, E.H., Hoberg, "Physiology of Skiing", Berickte uber die Gres.Physiol., Vol. 146, 1951, p.229.

38. Astrand, op. cit., p. 309.

39. Andersen, K.L., Nord. med., Vol. 54, 1955, pp. 1246-48.

40. Astrand, op. cit., p. 314.

41. Astrand, Saltin, op. cit., p. 978.

42. Ibid., p. 979.

43. Le Blanc, J.A., "Use of Heart Rate as an Index of Work Output", J. Appl. Physiol., Vol. 10, 1957, pp. 275-280.

44. Balke, Ware, loc. cit.

45. Consolazio, Johnson, Pecora, op. cit., p. 342.

46. Wyndham, Strydom, Maritz, Morrison, Peter, Potgieter, loc. cit.

47. Brouha, L., Gallagher, "A Simple Method of Testing Physical Fitness in Boys", Research Quarterly, Vol. 14, 1943, pp. 23-30.

48. Robinson, Edwards, Dill, loc. cit.

49. Astrand, op. cit., p. 324.

50. Robinson, Edwards, Dill, loc. cit.

51. Astrand, op. cit., p. 323.

52. Ibid.

53. Brouha, L., Heath, C.W., New England Journal of Medicine, Vol. 228, 1933, p. 473.

54. Lewis, B.M., Morton, J.W., J. of Appl. Physiol., Vol. 7, 1954, p. 309.

55. Astrand, op. cit., p. 318.

56. Slonim, Gillespie, Harold, loc. cit.

57. Rushmer, R.F., Cardiovascular Dynamics, 2nd Ed., W.B. Saunders Co., Philadelphia and London, 1961, pp. 238-296; pp. 38-43.

58. Scher, A.M., "Excitation of the Heart", Handbook of Physiology, Section 2, Circulation, Vol. 1, Washington, D.C., 1962, pp. 323-26.

59. Cureton, T.K., Physical Fitness of Champion Athletes, U. of Illinois Press, Urbana, 1951, pp. 137-62.

60. Ibid.

61. Hoogerwerf, S., "Elektrekardiographische untersuchungen der Amsterdamer Olympiadekampfer", Arbeitsphysiologie, Vol. 2, 1929, pp. 61-76.

62. Cooper, E.L., O'Sullivan, J., Hughes, E., "Athletics and the Heart, An Electrocardiographic and Radiological Study of the Response of the Healthy and Diseased Heart to Exercise", Med. J. Australia, Vol. 1, 1937, pp. 569-79.

63. Carlisle, F., Carlisle, U., "T Wave Changes in Strenuous Exercise", Track Technique, No. 2, Dec. 1960.

64. Hunt, E.A., "Electrocardiographic Study of Twelve Champion Swimmers Before and After 110 Yard Sprint Swimming Competition", Can. Med. Assoc. Journal, Vol. 88, 1963, pp. 1251-53.

65. Cureton, loc. cit.

66. Hoogerwerf, loc. cit.

67. Wolf, J.G., "Effect of Posture and Muscular Exercise in the Electrocardiogram", Research Quarterly, Vol. 24: No. 4, Dec. 1953, pp. 323-326.

68. Rose, K.D., Dunn, F.L.,"Physiology of Running Studied by Use of Radiotelemetry", The Journal of Sports Medicine and Physical Fitness, published after 1964.

69. Banister, E.W., Cureton, T.K., Abbott, B.C., Pollard, J.W., "A Comparative Study of the Brachial Pulse Wave and the Time Derivative Among Athletic, Normal and Pathological Subjects", J. of Sports Medicine and Physical Fitness, Vol. 6, No. 2, June 1966, pp. 92-99.

70. Brown, S.R., Banister, E.W., Dower, G.E., "Time Derivatives of the Carotid Pulse Wave and Phase Plane Analysis of Cardiovascular Condition", presented at CAHPER Convention, Fredericton, N.B., June 1965.

71. Gleason, W.L., Braunwald, E., "Studies on the First Derivative of the Ventricular Pressure Pulse in Man", J. of Clinical Investigation, Vol. 41, 1962, pp. 80-91.

72. Hyman, G., Winsor, T., "What Can Be Found in Arterial Pulse Waves", American Heart Journal, Vol. 61, 1961, pp. 424-426.

73. McDonald, D.A., Blood Flow in Arteries, London, Edward Arnold, 1960, p. 201.

74. Remington, J.W., Wood, E.H., "Formation of the Peripheral Pulse Contour in Man", J. of Appl. Physiol., Vol. 10, 1956-57, p. 433.

75. Bobskii, E.B., Karpman, V.L., Petrov, G.M., Sachkova, A.I., "Use of an Electronic Differentiating Device in Physiological Studies", Biophysics, Vol. 4, 1959, p. 102.

76. Dontas, A.S., Coltas, C.S., "Comparison of Simultaneously Recorded Inter-Arterial and Extra-Arterial Pressure Pulses in Man", Am. Heart J., Vol. 59, 1960, p. 576.

77. Hyman, Winsor, loc. cit.

78. Dontas, Coltas, loc. cit.

79. Starr, I., Ogawa, S., "A Clinical Study of the First Derivative of the Brachial Pulse", Am. Heart J., Vol. 65, 1962, pp. 482-94.

80. Warren, J.V., Leonard J., "Intravascular Pressure Recording", Methods in Medical Research, Vol. 7, Chicago, 1958, Year Book Publishers Inc.

81. Hyman, Winsor, loc. cit.

82. Rushmer, R.F., "Initial Ventricular Impulse", Circulation, Vol. 29, 1962, p. 282.

83. Wiggers, C.J., "Studies on the Consecutive Phases of the Cardiac Cycle", Am. J. of Physiol., Vol. 56, 1921, O. 415.

84. Starr, Ogawa, loc. cit.

85. Hyman, Winsor, loc. cit.

86. McDonald, D.A., Taylor, M.G., "Hydrodynamics of the Arterial System", Prog. Biophysics, Vol. 9, 1959, p. 105.

87. Wiggers, op. cit., pp. 427-30.

88. Ibid.

89. Harrison, T.R., Dixon, K., Russell, R.O., Bidway, P.S., Coleman, H.N., "The Relation of Age to the Duration of Contraction, Ejection and Relaxation of the Normal Human Heart," Am. Heart J., Feb. 1964, pp. 189-99.

90. Starr, Ogawa, loc. cit.

91. Neal, N.J., Halpern, W., Reeves, T.J., "Velocity and Acceleration Pressure Changes in Heart and Arteries", J. Appl. Physiol. Vol. 15, 1960, pp. 747-49.

92. Banister, Cureton, Abbott, Pollard, loc. cit.

93. Starr, Ogawa, loc. cit.

94. Ibid.

95. Banister, Cureton, Abbott, Pollard, loc. cit.

96. Robinson, B., "The Carotid Pulse I: Diagnosis of Aortic Stenosis by External Recordings", British Heart J., Vol. 25, 1963, pp. 51-60.

97. Starr, Ogawa, loc. cit.

98. Ibid.

99. Dontas, Coltas, loc. cit.

100. Banister, Cureton, Abbott, Pollard, loc. cit.

101. Weissler, A.M., Peeler, R.G., "Relation Between Left Ventricular Ejection Time, Stroke Volume and Heart Rate in Normals", Am. Heart Journal, Vol. 62, 1961, p. 367.

102. Brown, Banister, Dower, loc. cit.

103. Consolazio, Johnson, Pecora, op. cit., p. 340.

104. Brouha, L., "Training", Science and Medicine of Exercise and Sports, Harper Bros. Publishers, New York, 1960, pp. 409-10.

105. Gerschler, W., "Training for Middle and Long Distance Running", Track Technique, Vol. 17, Sept. 1964, p. 530.

106. Brouha, op. cit., p. 404.

107. Hettinger, Muller,"Muskelleistung und Muskeltraining", Arbeitsphysiologie, Vol. 15, 1953, pp. 111-16.

108. Morgan, R.E., Adamson, G., Circuit Training, 1961, pp. 21-22, p.31.

109. Brouha, L. op. cit., p. 405.

CHAPTER III

METHODOLOGY

Test Parameters

The test battery measured the following parameters of fitness:

1. Electrocardiogram complexes - RS, T-wave, heart rate.
2. Simultaneous recording of the brachial pulse wave, its first derivative, the phase plane loop which indicates the phase relationship between the rising pulse amplitude and the rate of change of amplitude, and an electrocardiogram, allowing measurement of:
   - diastole filling time (DFT) (including the isovolemic relaxation period of systole)
   - brachial upstroke time (BUT)
   - maximum rates of change of pulse wave amplitudes, positive ($+\dot{p}$) and negative ($-\dot{p}$)
   - pulse ranges Pr
   - the range of the maximum rates of change of pulse wave amplitudes $\dot{Pr}$
   - the ratio of the maximum rate of positive change of pulse wave amplitude to the maximum rate of negative change $+\dot{p}/-\dot{p}$
   - the ratio of the pulse range to the range of maximum rates of change of pulse wave amplitudes $Pr/\dot{Pr}$
   - R-R interval
   - the time interval between the onset of ventricular depolarization Q and the onset of brachial upstroke. The interval includes an electromechanical lag, the isovolemic contraction time and the pulse transmission time.

3. Oxygen consumption (maximal test)
   - maximum oxygen consumption average over the ten minute basal and post-exercise periods
   - average oxygen consumption during the last three minutes of exercise
4. Leg, back, grip dynamometer strength tests
5. Time for a mile run
6. Circuit times and loads

Apparatus

Continuous recording of ECG complexes were made using radiotelemetry apparatus consisting of a FM transmitter (model 27-1) and receiver (model RB-27)[1] and a Sanborn 500 Viso-Cardiette recorder[2]. Beckman recording electrodes[3] were used.

The brachial pulse wave and its time derivative were recorded using a capacitance transducer over the brachial artery. The signal voltage, after being differentiated was displayed on two channels of a Tektronix 564 storage oscilloscope[4], both as the pulse wave and its time derivative respectively. The phase plane loop and electrocardiogram were recorded immediately after the pulse wave and its derivative had been photographed.

The Preston bicycle ergometer[5] used was a simple chain driven friction ergometer. A load of 16 kilograms on the brake wheel was utilized throughout the experiment.

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[1]Parks Electronics, Beaverton, Oregon.
[2]Sanborn Electrical Supply Co., Ltd., Montreal.
[3]Beckman Instrument Co., Palo Alto, California.
[4]Tektronix Instrument Co.
[5]Preston Instrument Corp., New York.

Certain considerations must be made when using a bicycle ergometer. When no load is on the ergometer, there is a friction loss in the chain and bearings. This friction loss increases when a load is applied due to the increased chain tension. As well, changes in speed during the work task prove to be a major source of error. During this study, effort was made to ensure the rider was maintaining the proper speed. The change in friction due to the changes in speed was determined.

The ergometer was enclosed in a closed-circuit re-breathing respirometer[1] (Figure 4) in which a controlled atmosphere could be maintained. Continuous gas analysis was performed by a Pauling gas analyzer[2].

The leg and back and the grip dynamometer were conventional models used in strength testing[3].

Subjects

The six subjects were experienced oarsmen who had not been in training for at least ten weeks prior to the initial testing. These athletes were highly competitive by nature and were definitely motivated since this programme commenced training for the 1966 World Championships. All six were single university students or recent graduates with an average age, height and weight of 24 years (range 21-27), 75 inches and 183 lbs. respectively.

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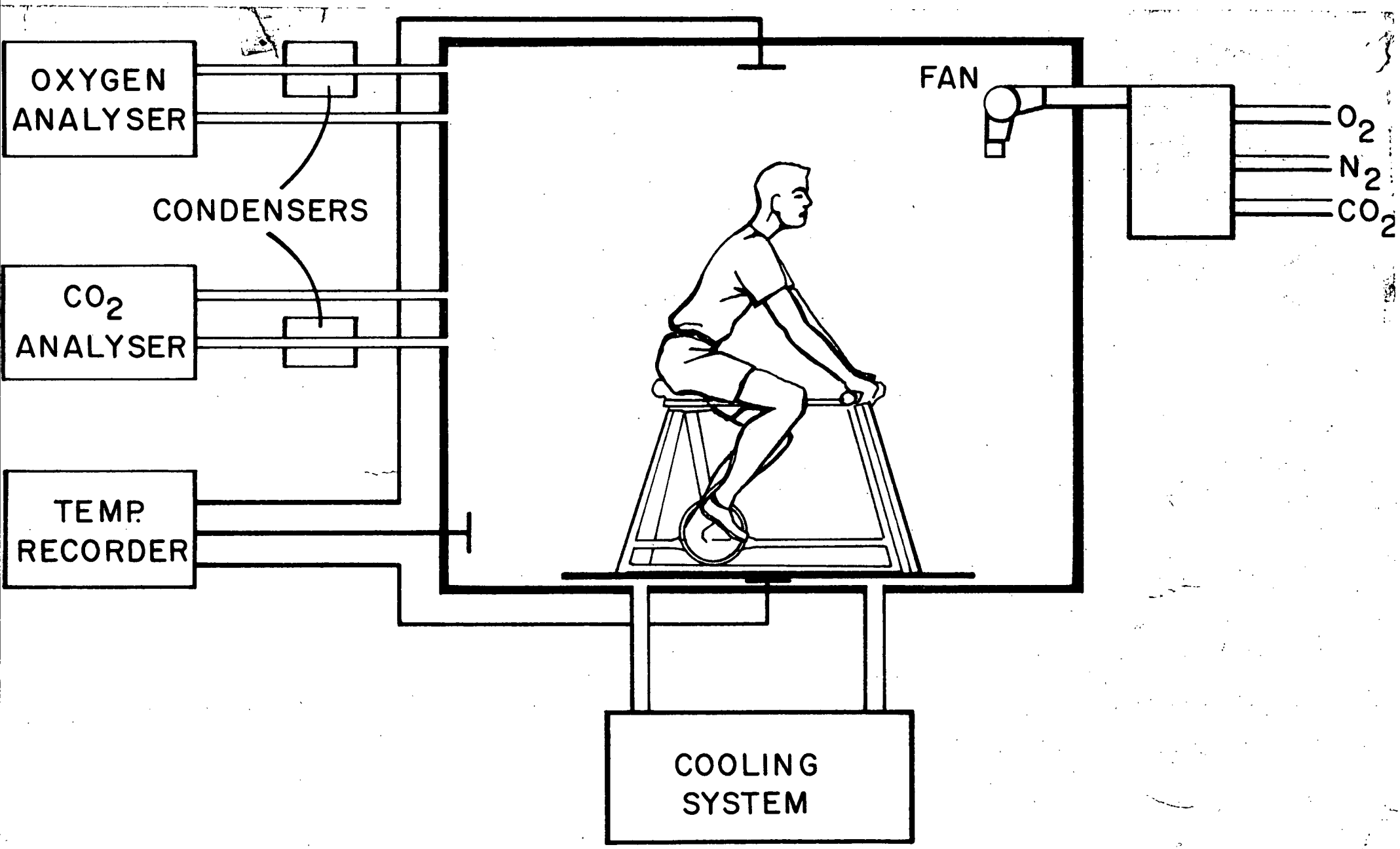
[1] Built and designed by Dr. H. Nordan, Dept. of Zoology, U.B.C.

[2] Beckman Instrument Co., Palo Alto, California.

[3] Layfayette Instrument Co., Indiana.

Figure 4 Closed Circuit Re-breathing Respirometer


OXYGEN ANALYSER
CONDENSERS
CO_2 ANALYSER
TEMP. RECORDER
FAN
O_2
N_2
CO_2
COOLING SYSTEM

Collection of the Data

Two complete pre-training testings were performed one week apart followed immediately by the eight week conditioning programme. The first post-training testing occurred the day after cessation of the conditioning programme and the second post-training testing one week later. A complete test battery took three days to administer, the submaximal tests and the dynamometer tests on day one, the maximal test on day two, and the mile run on day three. The test battery included the following tests:

Submaximal Work Test

A five minute step test was performed on a twenty inch bench at a stepping rate of thirty per minute. The subject was tested immediately after a normal night's sleep, the only physical stimulation preceding the test being that resulting from awakening and travelling to the laboratory. Here the subject lay comfortably for thirty minutes before any data were collected. During this time the electrocardiogram electrodes were placed on the upper third of the sternum and on the 5th intercostal space sublateral to the heart. The pressure transducer was attached by means of a strap just distal to the antecubital space on the forearm where the brachial artery approaches the surface. The artery was located by palpitation. All pre- and post-exercise data were obtained while the subject was lying in the supine position. Electrocardiogram complexes were monitored at selected intervals from five minutes before exercise until ten minutes after exercise. The brachial pulse wave, its first derivative, the phase plane loop, and the pulse wave-electrocardiogram tracing were recorded five minutes before exercise, immediately after exercise, and five and ten minutes after exercise. The temperature in

the laboratory averaged 71-74°F throughout the experiment.

Maximal Work Test

The bicycle ergometer ride to exhaustion was performed against a resistance of 16 kilograms. The subject, after resting in the sealed chamber for ten minutes commenced riding at 60.5 revs/min for three minutes, then increased the rate by 9.5 revs/min every minute until a velocity of 117.5 revs/min was recorded (at eight minutes). The subject then held this rate for as long as possible. The ride was timed but the subject was not aware of this time after the eight minute mark. Checks were made to ensure that the rider was maintaining the proper velocity. The gas analysis and electrocardiogram recordings were continuous from the moment of entry until release from the chamber.

Dynamometer Test

The dynamometer tests of leg and back strength, and the manuometer tests of grip strength are outlined in the text by Mathews (1).

Mile Run

All subjects ran a mile for time together on an outdoor quarter-mile track.

Circuit Time and Load

The circuit times and loads were recorded daily from the start of the conditioning programme.

Measurement of the Date

Oxygen Consumption

The oxygen consumed from the known volume of chamber air during the maximal bicycle ride was analyzed continuously by a Pauling

analyzer and recorded graphically. (Appendix A). The resting and recovery oxygen consumption were calculated as average values in l/min for their respective ten minute periods. The maximum oxygen consumption was determined as the average consumption over the last three minutes of exercise. All maximum and recovery values of oxygen consumption were recorded as values above the resting value. A two minute time lag occurred between the oxygen concentration in the chamber at any moment, and the recording of the concentration by the analyzer. This time lag was allowed for when all measurements were made from the recording. The wet and dry bulb temperature and the barometric pressure in the chamber were recorded during each ride. All gas volumes were corrected to standard temperature and pressure dry. The procedure for calculating the oxygen consumed is shown in Appendix A. Six rides were performed to determine the reliability of the analyzing equipment.

Electrocardiogram Complexes

The equipment used to receive, transmit, amplify and record the heart voltages is described above. The recording electrodes were placed on the upper third of the clavical and sublateral of the heart, between the 5th and 6th ribs.

The recording of ECG complexes was continuous from the resting state throughout exercise and until ten minutes recovery for both the maximal and submaximal tests. Normal standardization procedure was followed before each ECG recording. The measurement of the T-wave, $\leq$ RS and heart rate were made during selected intervals, these being at 5 minutes resting, immediately before exercise, every 30 seconds during the first two minutes of exercise and recovery, and every minute during

the remainder of exercise and recovery. Five measurements were averaged to give one mean value for each parameter at each selected interval. Measurements were made with vernier calipers to the nearest 10th of a millimeter. A line was drawn from Q-Q (Figure 1) in an attempt to establish an accurate base line for measurement of the T-wave. The RS amplitude was measured as being one deflection.

The Brachial Pulse Wave, the First Derivative and the Phase Plane Loop

Three photographs indicating the pulse wave and its derivatives were taken from the oscilloscope during each of the periods of rest and immediate, 5 minute, and 10 minute recovery from performance of the 5 minute step test. The three photographs offered permanent records of the simultaneously recorded pulse wave and its first derivative, the phase plane loop, and the simultaneously recorded pulse wave and electrocardiogram (Figure 2).

The brachial upstroke time, reduced ejection period and diastolic filling time were measured first as intervals (AB-BD-DA, Figure 2) respectively along the base line of the first derivative and then were converted to temporal values by utilizing the known velocity of the oscilloscope trace beam. The time interval Q-brachial upstroke was calculated by the same method.

Since the abscissa of the loop tracing represents increasing pulse pressure, the range of pulse pressure Pr was measured as the distance between the two widest points on the loop. Since the ordinate of the loop tracing represents the rate of change of pulse pressure $\dot{p}$, the range of $\dot{p}$, $\dot{P}r$ was measured as the distance between $+\dot{p}$ and $-\dot{p}$. The pulse range Pr of each loop was divided by an arbitrary value of ten to

establish a basic unit of measurement for that loop. The mid-point between the maximum and minimum pressure was the intersection point for the ordinate and abscissa, thus allowing five units to the left and to the right of the ordinate along the abscissa. Since all loops were divided into ten units along the abscissa and the co-ordinates of any point on a loop could be expressed in terms of its basic unit, the co-ordinates of points such as $+\dot{p}$ and $-\dot{p}$ on one loop could be compared to the co-ordinates of the same points on another loop.

Conditioning Programme

The programme was performed on five consecutive days each week, the circuit and weight training on days one, three and five, and three and one-half miles of sustained running on each of days two and four. The programme continued for eight weeks and allowed forty workouts. A daily record of circuit time and load and a record of the strength exercises were kept to provide an indication of the muscular endurance, stamina and strength improvement (Appendix B).

REFERENCES

1. Mathews, D.K., Measurement in Physical Education, W.B. Saunders Co., Philadelphia and London, 1963, pp. 65-68.

CHAPTER IV

PRESENTATION OF RESULTS

Introduction

The oxygen consumption, electrocardiogram, pulse wave, stamina, strength and muscular endurance results are presented below. T_1 and T_2 are pre-training test batteries and T_3 and T_4 post-training test batteries. All batteries contained the same tests. The data have been expressed in graphical and tabular form to facilitate interpretation. A statistical analysis of all the fitness parameters had been considered both to determine which parameters correlated highly with each other and to isolate those parameters which best evaluated and indicated the fitness status or changes in such resulting from training. Such a mass correlation cannot be reliably performed due to the limited number of subjects available for study. Isolation of the most sensitive indicators of fitness change is also impractical under the existing research design. The framework of this study does allow the determination of those parameters which changed as a result of training. It does not consider the importance of the degree of change of the parameters - that is, a very small change in one parameter as a result of training might be as indicative of fitness change as a large change in another parameter. For these two reasons, an analysis of variance or other similar statistical procedure was not felt to improve substantially the techniques already employed in determining which parameters indicated changes in fitness resulting from training. The means and standard deviations of the pre- and post-training group scores for each variable have been presented. A total of 42 t-tests were performed to compare 42 cardiovascular variables with respect to the significance of differences between their pre- and post-training scores.

Reliability of the Measures

One individual repeated a bicycle ergometer work task on six separate occasions and the oxygen cost of each performance was determined by a Beckman gas analyzer. Means and standard deviations of 2.61 $\mp$ 0.17 l/min and 0.57 $\mp$ 0.11 l/min were determined for measurements made during exercise and recovery from exercise respectively. The oxygen cost of performing a bicycle ergometer work task was determined by both Beckman and Scholander analysis methods on four occasions. The mean consumption and standard deviation for the task was 2.82 $\mp$ 0.01 l/min (Beckman) and 2.81 $\mp$ 0.18 l/min (Scholander).

T-wave and $\measuredangle$ RS measurements were made on six successive days on one subject in the resting state. The mean T-wave and $\measuredangle$ RS amplitude height was 7.4 $\mp$ 0.88 and 18.0 $\mp$ 1.73 respectively. Ten successive T-wave and $\measuredangle$ RS amplitude measurements were made from one resting tracing. The means and standard deviations of these were 5.8 $\mp$ 0.65 and 17.5 $\mp$ 0.66 respectively.

A resting loop tracing was recorded from one individual on twelve occasions. From each loop, the y co-ordinate of $\mp \dot{p}$ and the ratios $+\dot{p}/-\dot{p}$ and $Pr/\dot{P}r$ were determined. The means and standard deviations of these twelve measurements were:

	$+\dot{p}(y)$	$-\dot{p}(y)$	$+\dot{p}/-\dot{p}$	$Pr/\dot{P}r$
Mean	4.89	1.77	2.87	1.52
Standard deviation	0.71	0.30	0.71	0.13

Oxygen Consumption Data

Table II indicates that the mean maximal oxygen consumption in

T_1 and T_2 was 4.03 and 4.33 l/min respectively or 47.80 and 51.62 ml/kg/min respectively compared to the T_3 and T_4 values of 4.48 and 4.40 l/min respectively or 53.61 and 51.81 ml/kg/min respectively. The pre-training mean was 4.12 $\pm$ 0.33 l/min or 49.15 $\pm$ 5.57 (SD) l/min compared to values of 4.47 $\pm$ 0.56 l/min and 52.70 $\pm$ 7.35 ml/kg/min after training. Generally, with training, maximum and recovery oxygen consumption did not change significantly (Figures 5,6). The greatest consumption usually occurred during the second last minute of the ride. The average heart rate at which it occurred was lower after training than before - 177.5 $\pm$ 10.7 b/min compared to 185.8 $\pm$ 12.3 b/min. The lowest average heart rate for the group, 175 b/min, occurred at T_3 when the group average for maximum oxygen consumption was highest. The all-out ride mean time immediately after cessation of the eight weeks of training (T_3) was the shortest of all test rides but the ride time one week later (T_4) was longer and similar to pre-training rides T_1 and T_2.

Electrocardiogram Data

It appears that a basic pattern of T-wave amplitude variation occurs during submaximal (Figure 7) and maximal (Figure 8) exercise and recovery from exercise. Generally, as exercise begins, a decrease in T-wave amplitude occurs up to a certain point followed by a steady increase during the rest of the work period. The increase continues during recovery for one or two minutes resulting in formation of a peak amplitude which is usually well above the resting value. Following the peak, there is a steady amplitude decrease until the resting value is reached. This is usually within five minutes for submaximal and ten minutes for maximal exercise. Imposed on the basic pattern are characteristic individual

TABLE II

MAXIMUM OXYGEN INTAKE, HEART RATE AND TIME TO EXHAUSTION BEFORE (T_1,T_2) AND AFTER (T_3,T_4) TRAINING, FOR SIX SUBJECTS RIDING A BICYCLE ERGOMETER AT INCREASING RATES (TABLE III) AGAINST A CONSTANT RESISTANCE OF 16 KG.

Test	Subject	Resting $\dot{V}o_2$ l/min	Max.$\dot{V}o_2$ l/min	Max.$\dot{V}o_2$ ml/kg/min	Recovery $\dot{V}o_2$ l/min	Heart Rate at Max.$\dot{V}o_2$ b/min	Max.Heart Rate During Exercise b/min	Ride Time Until Exhaustion min:sec
1	GH	0.42	4.02	44.57	0.73	206	210	15:05
	RF	0.38	3.17	42.90	0.62	200	200	20:00
	RJ	0.31	4.78	55.84	0.84	182	182	16:40
	DS	0.41	3.35	40.45	0.67	180	185	11:20
	MW	0.27	4.35	45.93	0.95	180	185	11:18
	BS	0.15	4.50	57.11	0.79	177	190	11:28
2	GH	0.32	4.87	54.60	1.10	199	199	14:56
	RF	0.46	3.54	48.83	1.02	199	200	18:35
	RJ	0.29	4.82	56.97	0.73	178	185	18:21
	DS	0.33	4.31	52.05	0.59	174	177	11:05
	MW	0.30	4.56	48.15	0.92	175	185	12:39
	BS	0.36	3.87	49.11	0.77	176	185	11:43
3	GH	0.22	5.19	58.05	1.33	190	190	12:30
	RF	0.37	4.48	59.89	0.62	180	187	12:56
	RJ	-	-	-	-	-	-	-
	DS	0.33	3.44	39.86	0.62	154	170	9:45
	MW	0.29	4.76	50.16	0.73	177	184	11:30
	BS	0.29	4.88	60.07	0.92	174	180	10:15
4	GH	0.27	5.20	58.16	0.88	184	190	13:25
	RF	0.21	4.26	56.95	0.63	196	200	20:00
	RJ	0.37	4.73	55.26	0.76	177	180	15:52
	DS	0.43	3.73	43.22	0.58	175	180	12:15
	MW	0.51	4.29	45.21	0.77	172	178	9:30
	BS	0.30	4.21	52.04	0.82	174	180	11:13

(Cont'd).....

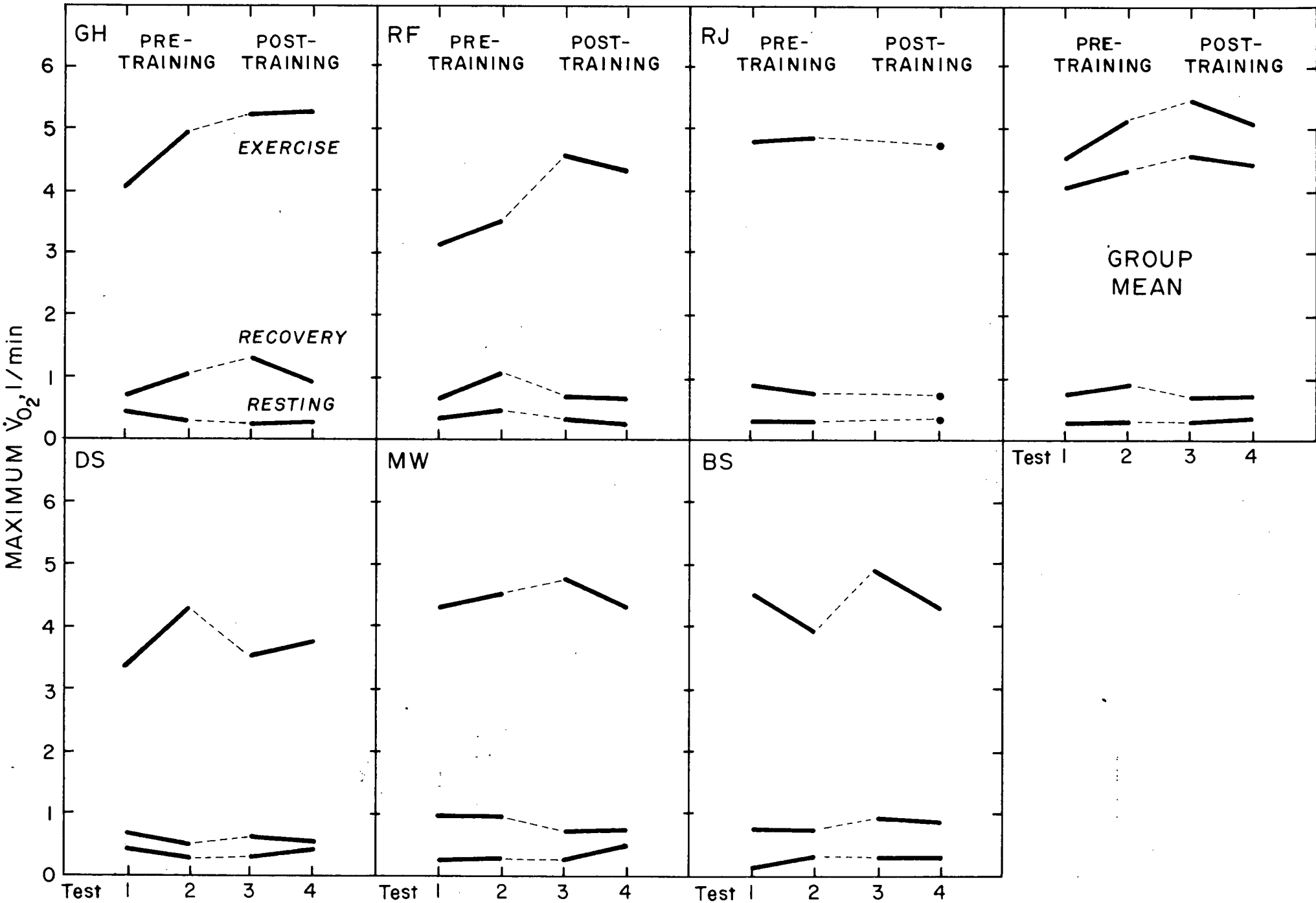
Test	Group Mean	Resting $\dot{V}O_2$ l/min	Max. $\dot{V}O_2$ l/min	Max. $\dot{V}O_2$ ml/kg/min	Recovery $\dot{V}O_2$ l/min	Heart Rate at Max. $\dot{V}O_2$ b/min	Max. Heart Rate During Exercise b/min	Ride Time Until Exhaustion min:sec
1		0.31	4.03	47.80	0.76	187.5	192.0	14:19
2		0.34	4.33	51.62	0.86	183.5	189.0	14:33
3		0.30	4.48	53.61	0.64	175.0	182.2	11:23
4		0.35	4.40	51.81	0.74	179.8	184.7	13:47
1 & 2		0.34 ± 0.01	4.12 ± 0.33	49.15 ± 5.57	0.81 ± 0.17	185.8 ± 12.3	191.0 ± 9.8	
3 & 4		0.33 ± 0.90	4.47 ± 0.56	52.90 ± 7.35	0.79 ± 0.21	177.5 ± 10.7	183.5 ± 7.9	

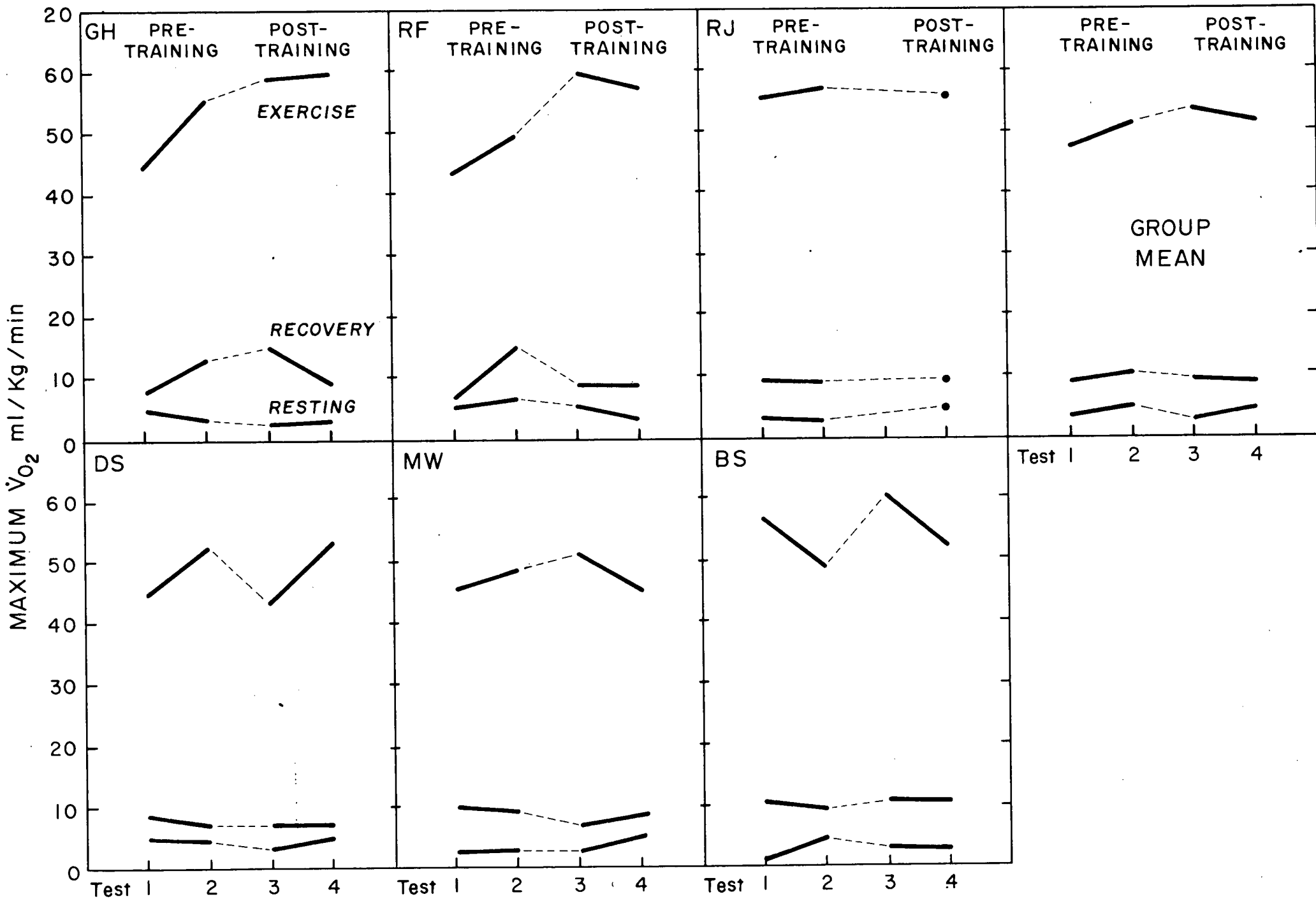
TABLE III

MAXIMAL TEST - BICYCLE ERGOMETER RIDE TO EXHAUSTION PERFORMED AGAINST A CONSTANT LOAD OF 16 KG BUT AT INCREASING PEDALLING RATES. BY EIGHT MINUTES, THE PEDALLING RATE OF 117.5 RPM WAS REACHED AND THEN MAINTAINED UNTIL EXHAUSTION OCCURRED

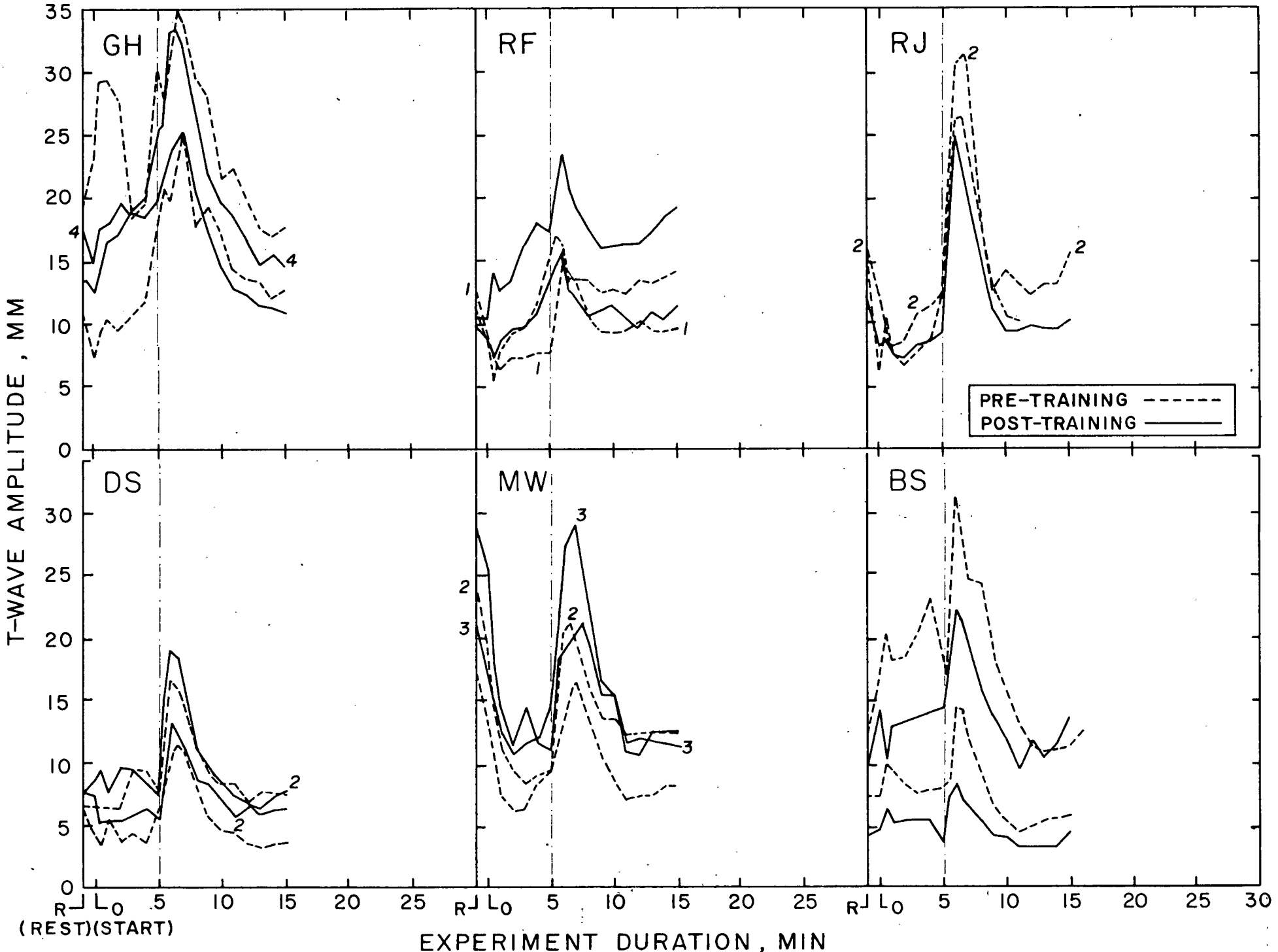
Ride Time min	Pedalling Rate rpm	Work Rate kg/m/min
0 - 3	60.5	735
3 - 4	70.0	850
4 - 5	79.5	960
5 - 6	89.0	1072
6 - 7	98.5	1190
7 - 8	108.0	1300
8 -	117.5	1415

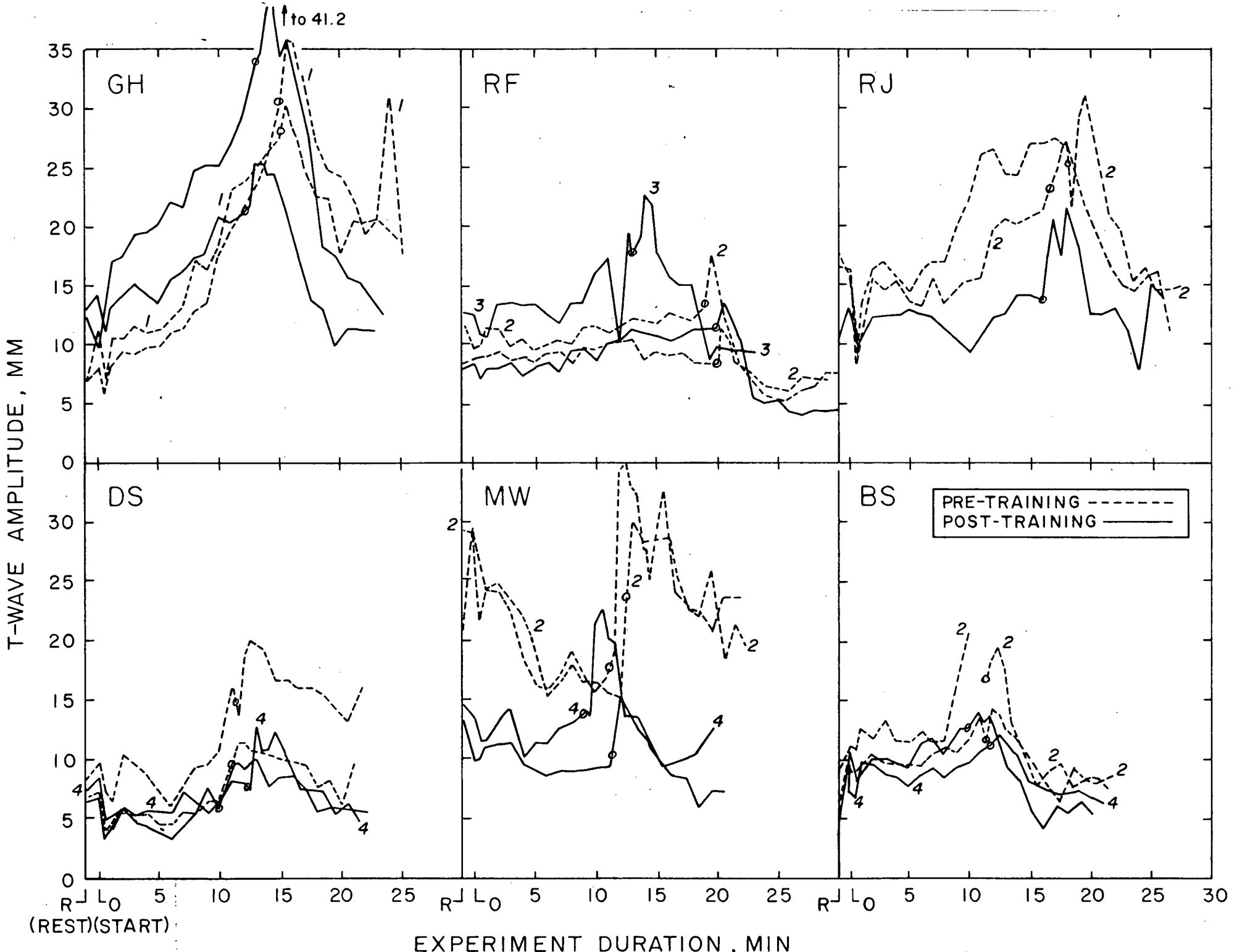
Figures 5,6 Resting, maximum, and recovery oxygen consumption as measured before, during and after an exhaustive ride on a bicycle ergometer. The data was collected on six oarsmen before (T_1,T_2) and after (T_3,T_4) eight weeks of training.


GH
PRE-TRAINING
POST-TRAINING
EXERCISE
RECOVERY
RESTING
RF
RJ
GROUP MEAN
DS
MW
BS
MAXIMUM $\dot{V}_{O_2}$, l/min
Test 1 2 3 4
0 1 2 3 4 5 6


GH
PRE-TRAINING
POST-TRAINING
EXERCISE
RECOVERY
RESTING
RF
RJ
GROUP MEAN
DS
MW
BS
MAXIMUM $\dot{V}_{O_2}$ ml/Kg/min
0
10
20
30
40
50
60
Test 1 2 3 4

Figures 7,8 Pattern of T wave amplitude change from rest during submaximal (Figure 7) and maximal (Figure 8) exercise and recovery from exercise for six oarsmen. Pre-training values (T_1,T_2) are represented by dotted lines. Post-training values (T_3,T_4) are represented by solid lines. Cessation of exercise during the maximal test occurred at the circled points, and during the submaximal test, after five minutes of exercise.


GH
RF
RJ
DS
MW
BS
PRE-TRAINING
POST-TRAINING
T-WAVE AMPLITUDE, MM
EXPERIMENT DURATION, MIN
R
(REST)
L
O
(START)
0
5
10
15
20
25
30
35


to 41.2
GH
RF
RJ
DS
MW
BS
PRE-TRAINING
POST-TRAINING
T-WAVE AMPLITUDE, MM
EXPERIMENT DURATION, MIN
R
L
O
(REST)(START)

variations. Inter-individual differences or differences from the basic pattern involve the duration and/or the degree of initial amplitude decrement at the onset of exercise, also the peak amplitude height during recovery. Several of the peak amplitude heights were greater than three millivolts. There does not appear to be any noticeable difference between the T-wave amplitude during maximal and submaximal work.

The RS amplitude appears to fluctuate continually during exercise and recovery but generally remains within a few millimeters of the resting value (Figures 9,10). Generally, post-training values are higher than corresponding pre-training values but the differences are not great and exceptions do occur. The resting value of the RS amplitude varies from one testing to the next but the ten minute recovery values are generally slightly larger than their respective resting values.

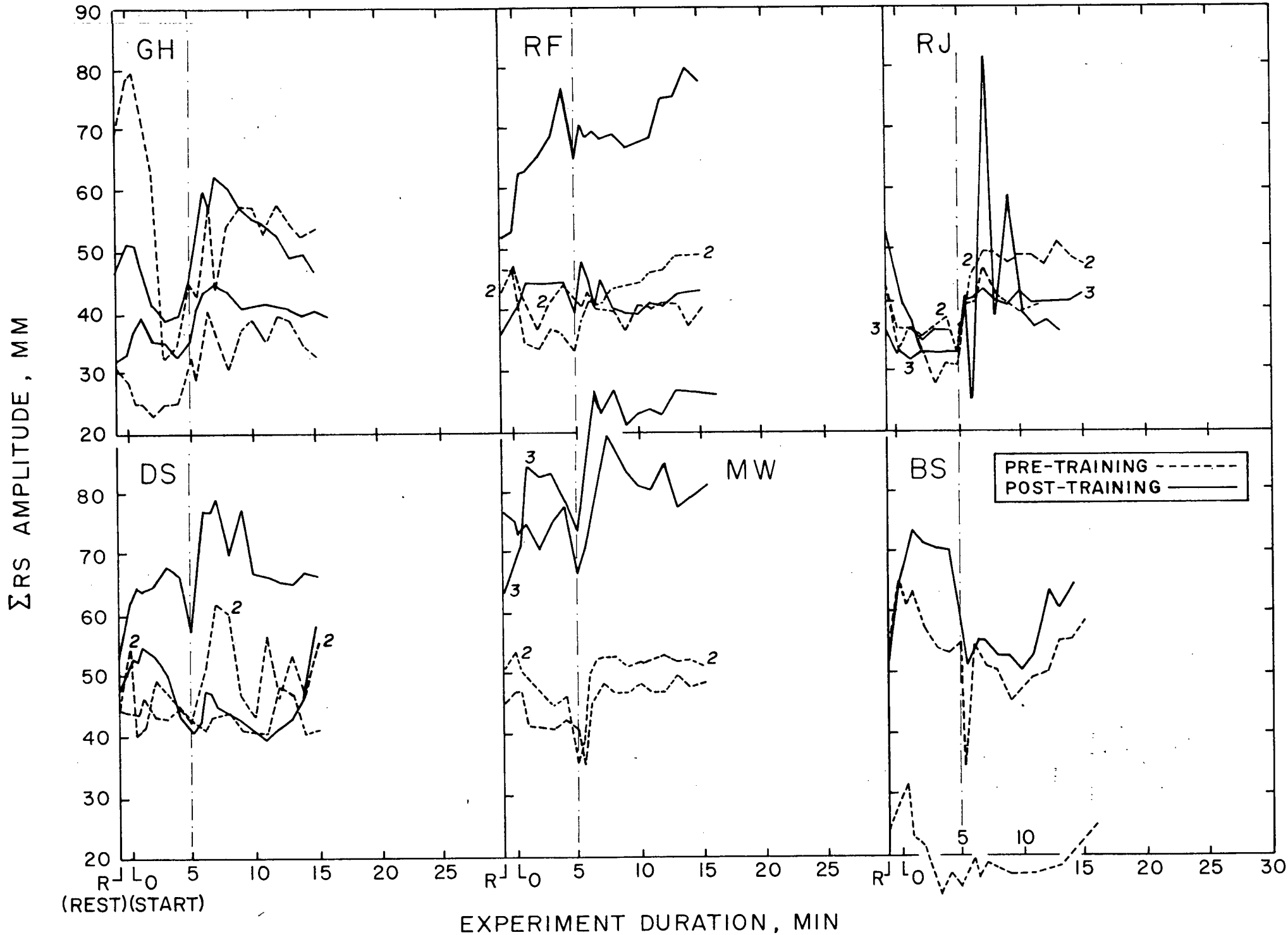
The heart rate for both maximal and submaximal tests after training was slower to increase with exercise, peaked at a lower level and recovered from exercise faster and to a lower level than before training (Figures 11,12). Before training, the mean maximal heart rate averaged 191 ± 9.8 b/min compared to 183 ± 7.9 b/min after training (Table II).

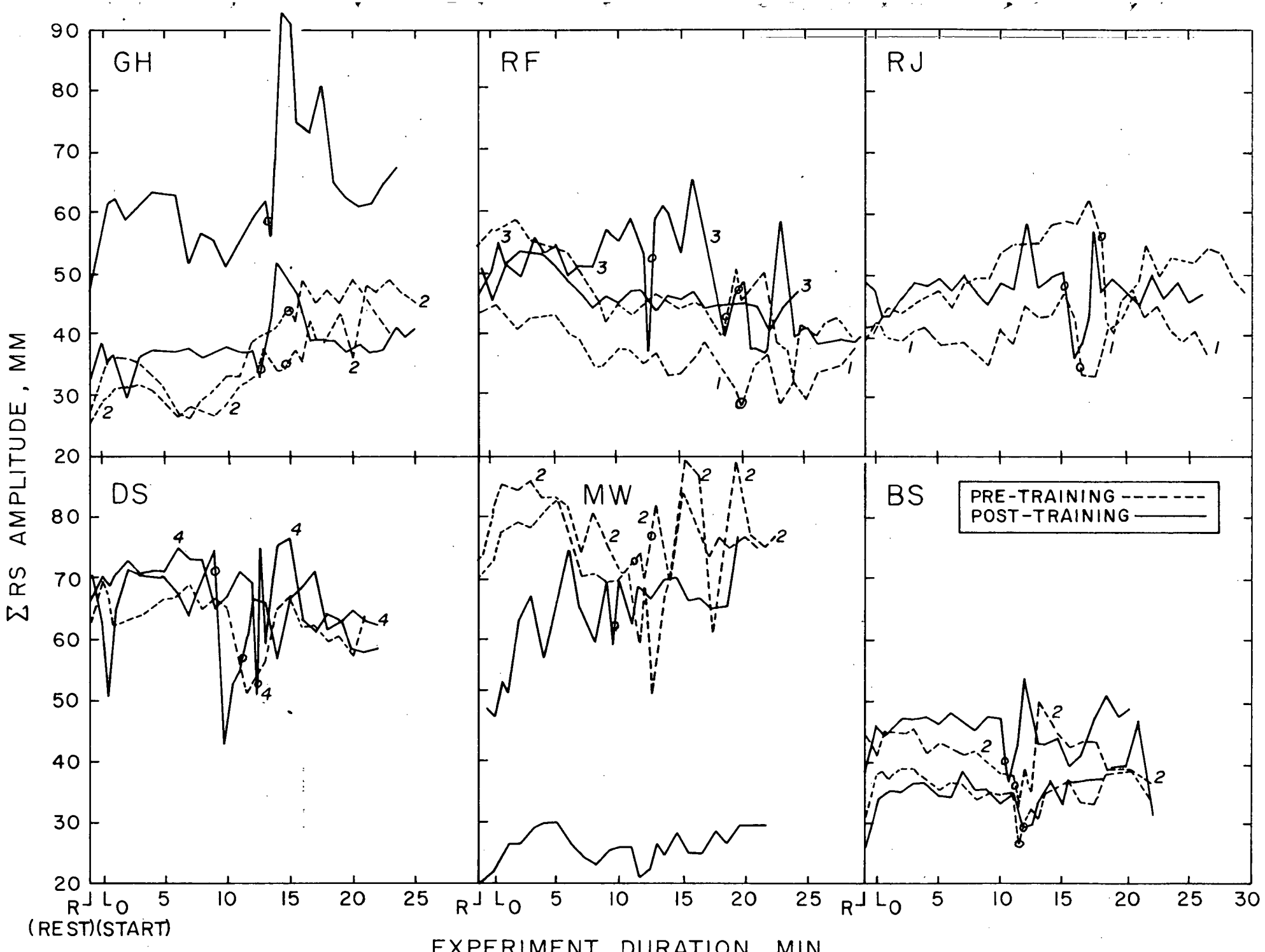
Figure 13 shows ECG tracings indicating T-wave and RS change during and following the five minute step test.

Brachial Pulse Wave, the First Derivative and Phase Plane Loop Data

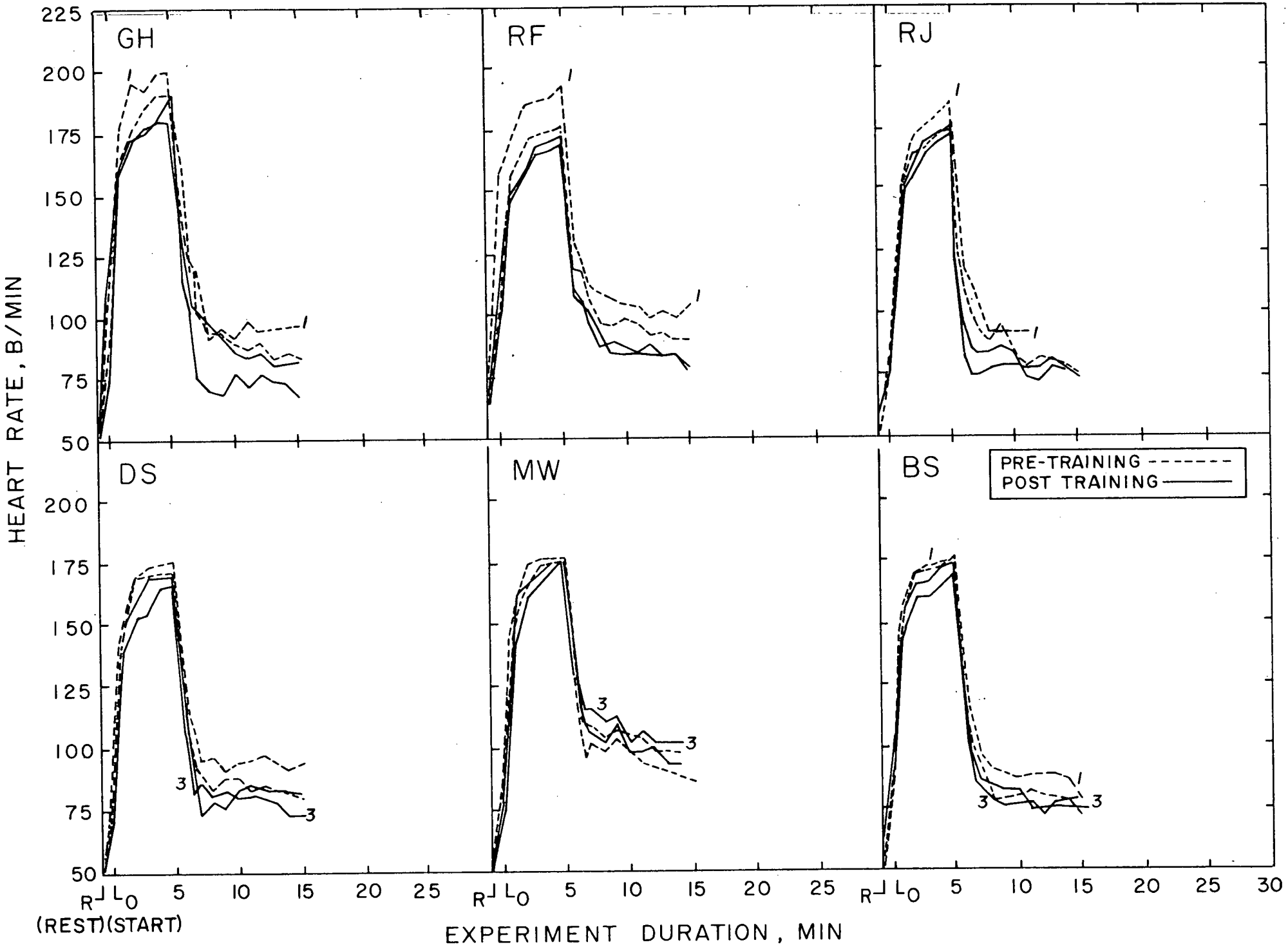
Since both the first time derivative of the pulse wave and the phase plane loop are derived from the primary wave, all three figures are directly related. Points on the primary wave can be located on the derivative and the loop. However, the first derivative and the loop each highlight certain aspects of the pulse that are perhaps not readily

Figures 9,10 Pattern of Σ RS amplitude change from rest during submaximal (Figure 9) and maximal (Figure 10) exercise and recovery from exercise for six oarsmen. Pre-training values (T_1,T_2) are represented by dotted lines. Post-training values (T_3,T_4) are represented by solid lines. Cessation of exercise during the maximal test occurred at the circled points, and during the submaximal test, after five minutes of exercise.


GH
RF
RJ
DS
MW
BS
PRE-TRAINING
POST-TRAINING
ΣRS AMPLITUDE, MM
EXPERIMENT DURATION, MIN
R (REST)
L (START)
90
80
70
60
50
40
30
20
5
10
15
20
25
30


GH
RF
RJ
DS
MW
BS
PRE-TRAINING
POST-TRAINING
ΣRS AMPLITUDE, MM
EXPERIMENT DURATION, MIN
R J L O
(REST)(START)

Figures 11,12 Pattern of heart rate change from rest during submaximal (Figure 11) and maximal (Figure 12) exercise and recovery from exercise for six oarsmen. Pre-training values (T_1,T_2) are represented by dotted lines. Post-training values (T_3,T_4) are represented by solid lines. Cessation of exercise during the maximal test occurred at the circled points, and during the submaximal test, after five minutes of exercise.


GH
RF
RJ
DS
MW
BS
PRE-TRAINING
POST TRAINING
HEART RATE, B/MIN
225
200
175
150
125
100
75
50
R
L
O
(REST)(START)
5
10
15
20
25
30
EXPERIMENT DURATION, MIN
1
3

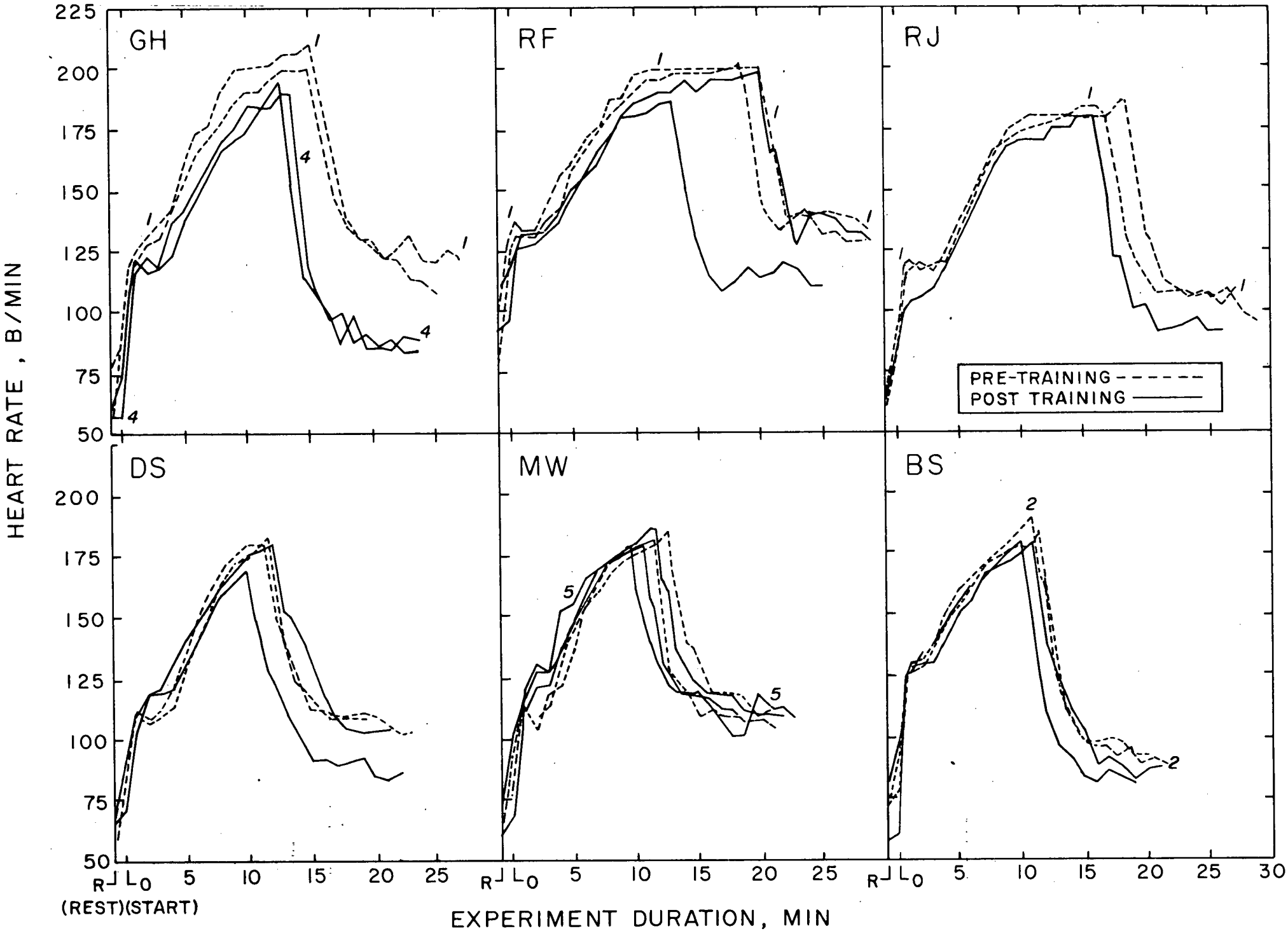
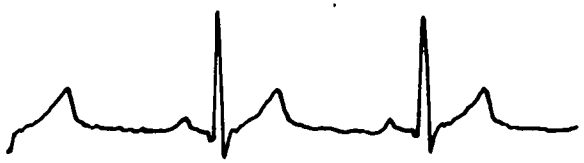

GH
RF
RJ
DS
MW
BS
PRE-TRAINING
POST TRAINING
HEART RATE, B/MIN
EXPERIMENT DURATION, MIN
(REST)(START)
225
200
175
150
125
100
75
50
5
10
15
20
25
30

Figure 13 Typical pattern of T wave and $\measuredangle$RS change during exercise and recovery from five minute step test, of subject R.J., post-training (T_4). Each section of ECG represents three seconds.



RESTING

START OF EXERCISE

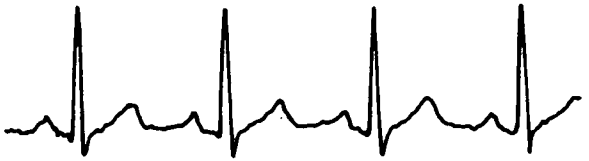
I MINUTE EXERCISE

5 MINUTES EXERCISE

I MINUTE RECOVERY

2 MINUTES RECOVERY

5 MINUTES RECOVERY



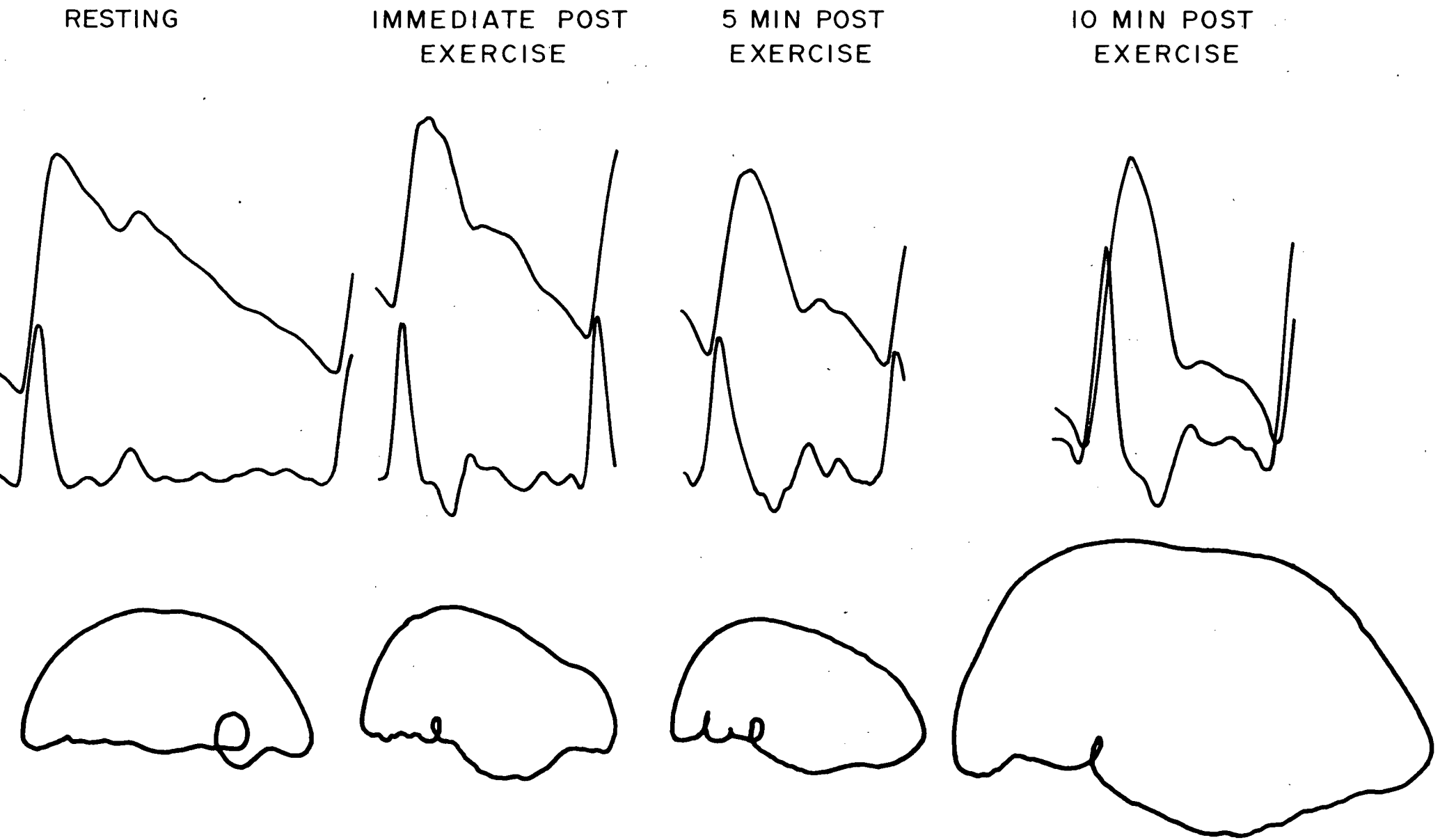
8 MINUTES RECOVERY

seen in the primary wave or each other. Therefore, the following description of the tracings as recorded during rest and recovery from exercise are presented with comments to indicate which of the tracings appear to express best the relationships important to this study (Figure 14).

The primary wave seen in the resting state in this study is characterized by a nearly verticle anacrotic rise to a high amplitude, a sharp primary peak, slight indication of a tidal wave on the catacrotic descent to the dicrotic notch, a prominent dicrotic notch and wave both of which appear early on the catacrotic slope and a slow relatively smooth descent to the base line. After exercise, the recovery waves retain most of the characteristics of the resting waves with three exceptions - the tidal wave is not obvious, if present at all, the dicrotic notch appears much lower on the catacrotic slope and the dicrotic notch and wave are present but less prominent. As recovery proceeds to the tenth minute, the catacrotic descent to the dicrotic notch becomes shorter.

The first time derivative of the primary wave allows measurement of the BUT, DFT and the heart cycle time. Definition of these measurements has been discussed. The form of the first derivative does not differ from that described by Starr (1) except that a distinct positive wave indicating the tidal wave often precedes the positive deflection indicating the dicrotic wave in the resting state. However, the recovery traces of the oarsmen are similar to the resting traces noted by Starr - that is, a fairly deep negative deflection follows the primary deflection and precedes the dicrotic wave deflection. Because the dicrotic notch and wave of the pulse appear shallow and reduced in the recovery traces, the

Figure 14 Pre-training pulse wave, first time derivative and phase plane loop of D.S. at rest and immediate, five minute and ten minute recovery from a five minute step test.


RESTING
IMMEDIATE POST EXERCISE
5 MIN POST EXERCISE
10 MIN POST EXERCISE

first derivative shows little amplitude on its dicrotic wave deflection. Small positive deflections sometimes occur after the dicrotic wave in the recovery tracings.

The phase plane loop is a useful indicator of the position and degree of the maximum rate of change of positive and negative pressure relative to the pulse pressure range. Values for these relationships have been presented. As well, the damping of the tidal wave observed on the recovery trace is readily seen on the loop -that is, the smooth catacrotic descent to the dicrotic notch is seen as a smooth negative concave curve leaving the base line at the point of maximum pressure and returning to it at the point of inscription of the dicrotic wave. The tidal wave can be seen in the resting trace as a negative concave wave immediately following the base line point of maximum pressure and preceding the negative concave wave representing the catacrotic descent to the dicrotic wave. The dicrotic wave seen from the loop is readily identified as being itself a tiny loop on the base line. The position of the dicrotic wave on the resting tracings is on the right side of the loop but the recovery traces clearly indicate the dicrotic wave to be on the left side of the loop. This is in accord with the primary wave and first derivative indications that the dicrotic notch and wave appear later on the catacrotic slope of the wave in the recovery traces as compared to their position on the resting traces. No attempt was made to determine at what pressure the dicrotic wave appeared.

Pre- and post-training resting pulse waves appear very similar. However, the form of the recovery (post-exercise) pulse might be a

valuable descriptive parameter in determining the degree of fitness of an individual. Generally, after a given exercise, post-training recovery pulse waves retain their normal resting form better than do pre-training recovery pulse waves (Figure 15). Recovery tracings of the untrained oarsmen are characterized by a very smooth (no tidal wave) and long catacrotic descent to a late dicrotic notch, rounded primary and dicrotic waves, the latter appearing to the far left of the early recovery loop, and little return to the normal wave pattern by ten minutes recovery. In contrast, post-training recovery tracings show general retention of the primary wave form, the tidal wave often being visible in the derivative, and a relatively early dicrotic notch and wave, indicated most clearly by the loop tracing (Figure 16) as being more towards the middle or the right of the loop. The primary wave often remains fairly sharp.

The DFT and the BUT can be expressed as temporal values or as a percentage of the R-R interval to correct for heart rate. Figure 17 and Table IV show that the resting BUT before and after training is relatively the same. Immediately after exercise when the heart rate has increased considerably from the resting value there is generally only a slight decrease in upstroke time with post-training times being usually slightly faster than pre-training times. As recovery proceeds, the BUT returns to the resting level.

The resting DFT is generally longer after training than before (Figure 17, Table IV). The early recovery DFT becomes faster with training and returns more quickly towards the resting value as recovery proceeds. The 10 minute recovery DFT is considerably faster than the

TABLE IV

AVERAGE BRACHIAL UPSTROKE TIME, DIASTOLIC FILLING TIME AND Q-BRACHIAL UPSTROKE INTERVAL FOR 6 OARSMEN BEFORE (T_1,T_2) AND AFTER (T_3,T_4) TRAINING, AT REST R, AND IMMEDIATE R_1, 5 MINUTE R_2, AND 10 MINUTE R_3 RECOVERY FROM 5 MINUTE STEP TEST, AS MEASURED FROM THE BRACHIAL PULSE WAVE .

		T_1 m sec	T_2 m sec	Mean T_1 T_2 m sec	T_3 m sec	T_4 m sec	Mean T_3 T_4 m sec
Brachial Upstroke Time	R	177	173	175 ± 24.1	178	163	171 ± 24.5
	R_1	143	142	143 ± 26.8	132	122	127 ± 32.3
	R_2	166	162	164 ± 19.5	167	167	167 ± 23.9
	R_3	174	190	182 ± 20.4	194	184	189 ± 24.4
Diastolic Filling Time	R	802	750	778 ± 159.9	1049	972	1011 ± 183.5
	R_1	282	378	330 ± 90.6	309	343	326 ± 131.4
	R_2	303	346	325 ± 72.9	368	374	371 ± 68.9
	R_3	352	368	346 ± 51.7	406	460	433 ± 92.1
Q-BU Interval	R		249	249 ± 23.5	237	240	238 ± 25.5
	R_1		188	188 ± 15.0	191	180	185 ± 17.3
	R_2		348	348 ± 23.0	222	243	233 ± 15.8
	R_3		236	236 ± 5.5	234	243	239 ± 21.7

Figure 15 A comparison of pre- and post-training pulse waves and their first derivatives of R.F. during immediate, five minute and ten minutes recovery from a five minute step test. The resting pulse wave before and after training had the same form. The post-training pulse waves show a faster return to the resting wave form than do the pre-training waves.

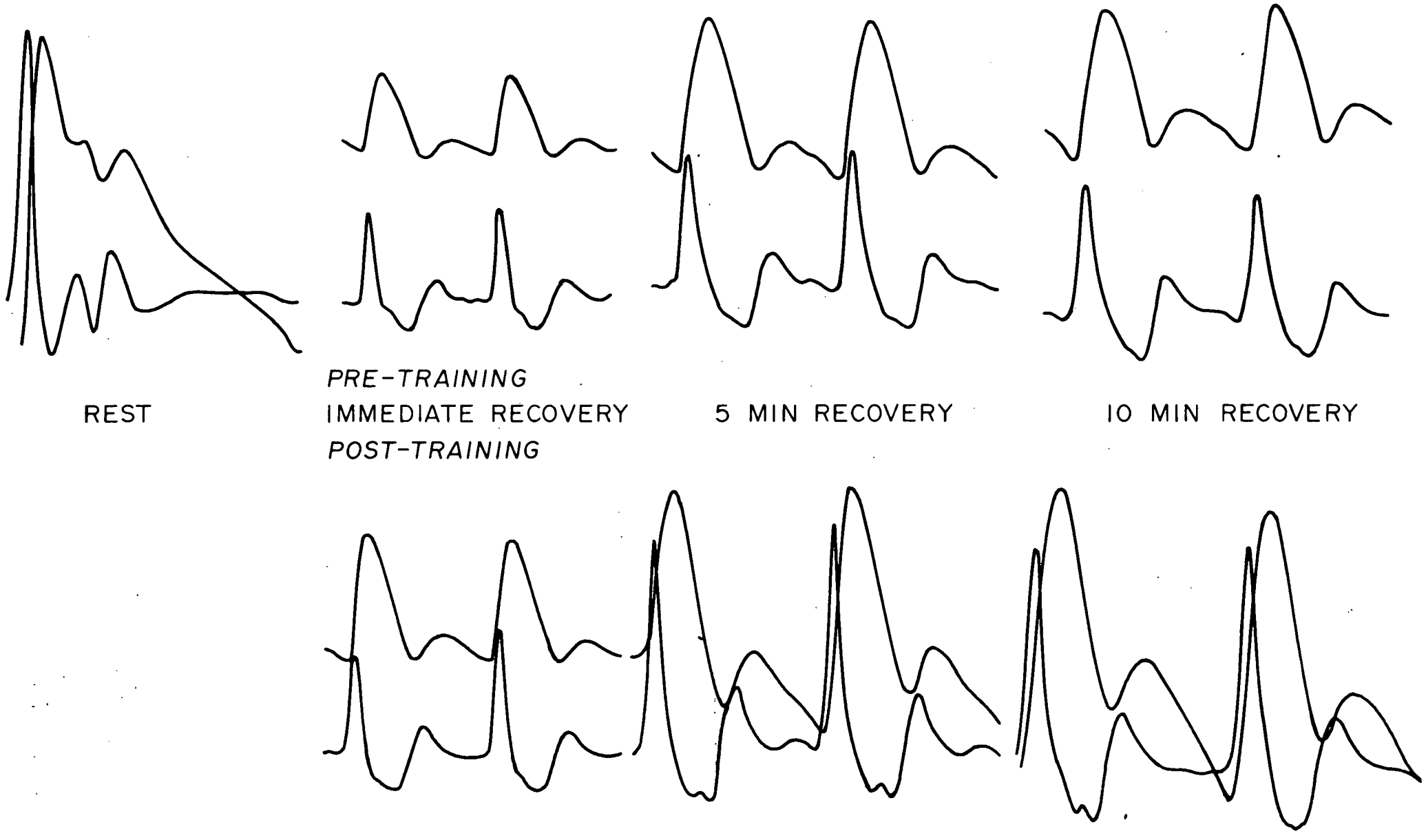
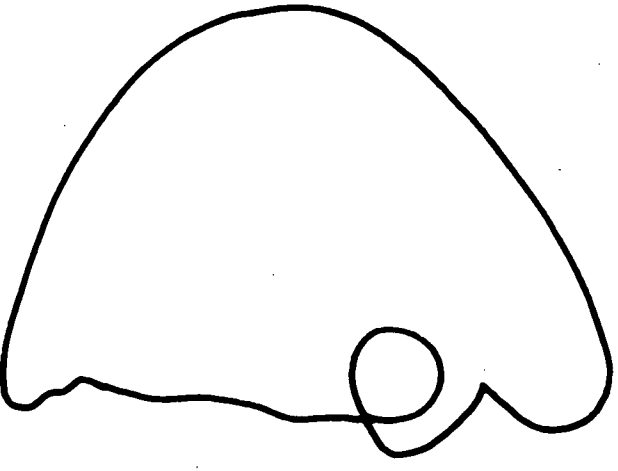
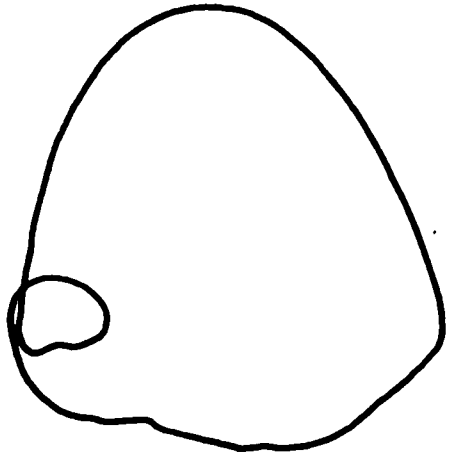

REST
PRE-TRAINING
IMMEDIATE RECOVERY
POST-TRAINING
5 MIN RECOVERY
10 MIN RECOVERY

Figure 16 A comparison of pre- and post-training phase plane loops of R.F. during immediate, five minute and ten minute recovery from a five minute step test. The resting loop before and after training had the same form. The post-training loops show a faster return to the resting wave form than do the pre-training waves.

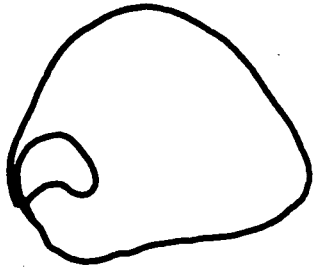


REST

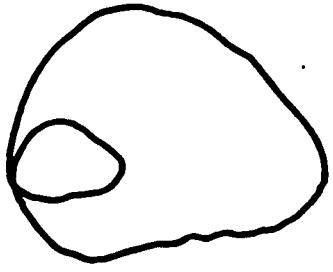


PRE-TRAINING

IMMEDIATE RECOVERY

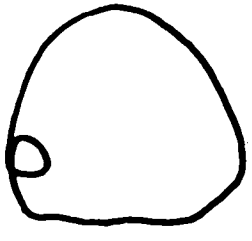


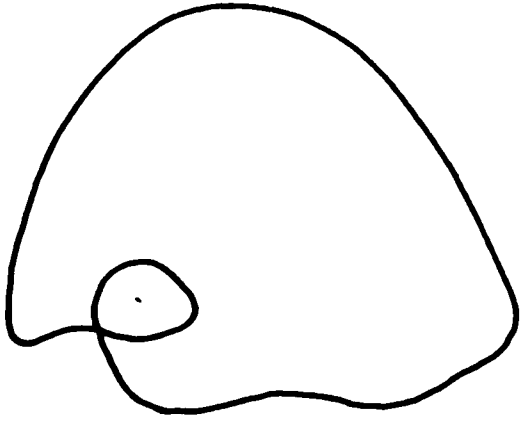
5 MIN RECOVERY



10 MIN RECOVERY

POST-TRAINING





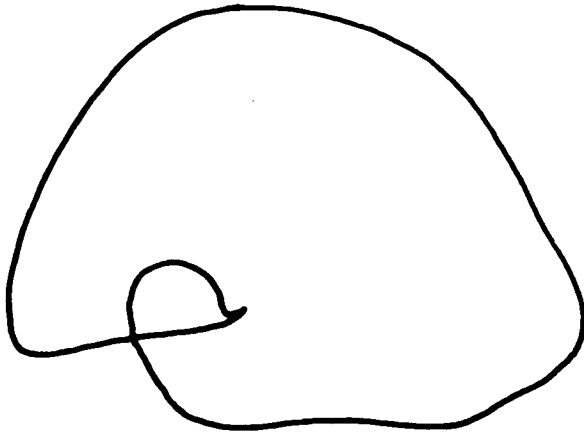
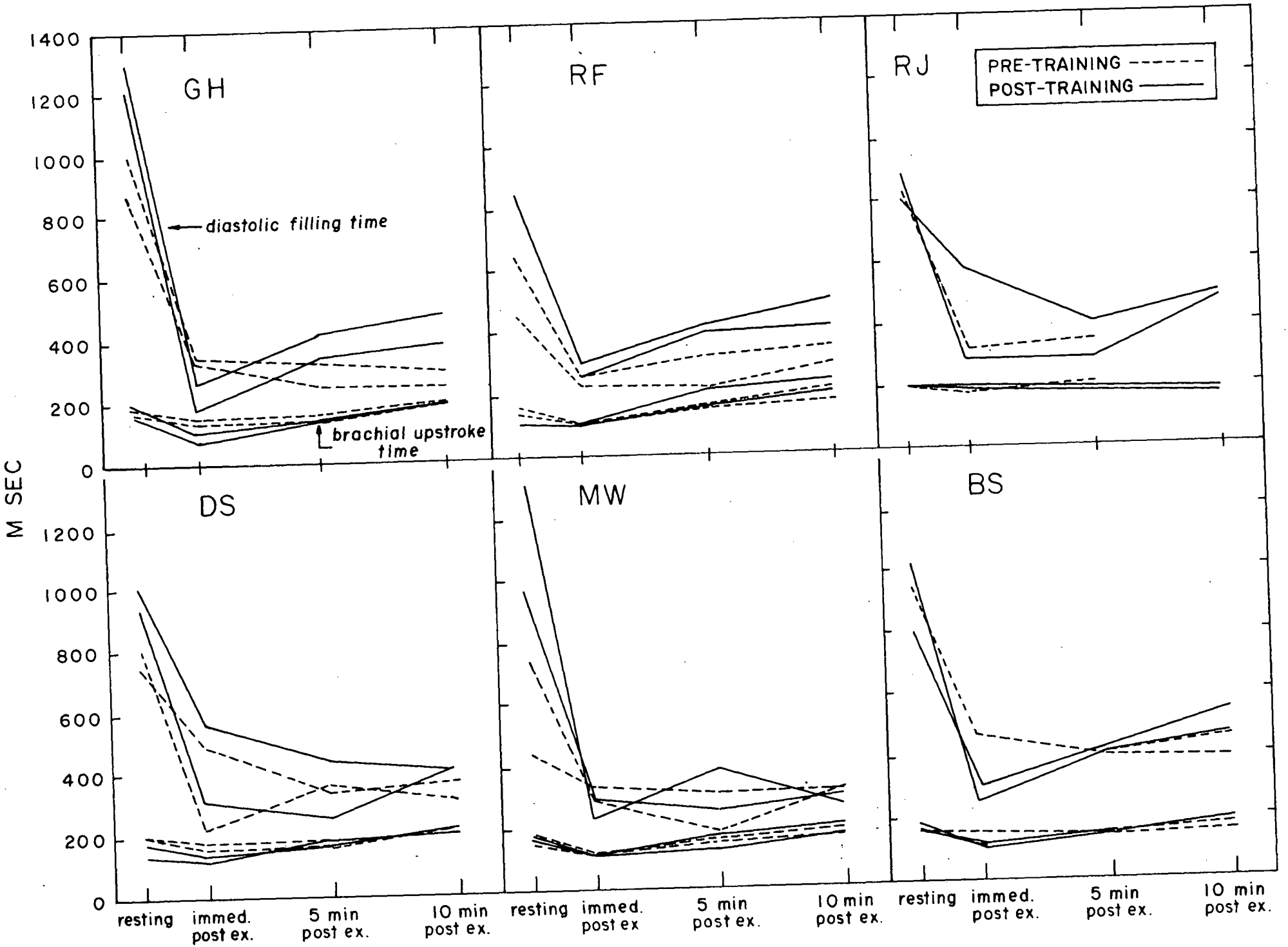


Figure 17 The diastolic filling time and brachial upstroke time at rest and immediate, five minute and ten minute recovery from a five minute step test, before (T_1,T_2) and after (T_3,T_4) training.


GH
RF
RJ
DS
MW
BS
PRE-TRAINING
POST-TRAINING
diastolic filling time
brachial upstroke time
M SEC
1400
1200
1000
800
600
400
200
0
resting
immed. post ex.
5 min post ex.
10 min post ex.

resting DFT.

Figure 18 shows that the BUT expressed as a percentage of the R-R interval in the resting state increases during the 10 minute recovery period. The time taken to reach maximum brachial pulse wave amplitude in the resting state (Table V) is 14.1% of the R-R interval before training compared to 12.2% after training. During recovery, the BUT increases from 21.5 to 25.0 per cent of the R-R interval for the untrained subjects compared to 18.9 to 21.9 per cent for the trained subjects.

The DFT percentage of the R-R interval during rest is greater after training than before. Figure 18 and Table V show that the DFT percentage is decreased immediately after exercise, generally decreases further by five minutes recovery and begins to return to the resting value by the ten minute recovery. In the resting state, the time proportion of each heart cycle to fill the ventricles is 65.1% in the untrained subjects and 71.2% in the trained subjects (Table VI). During recovery, the DFT decreases from 50.3% to 44.5% of the heart cycle time by five minutes in the untrained subjects compared to 48.3% to 46.2% in the trained subjects. By ten minutes recovery, the DFT percentage of heart cycle time increased to 47.1% in the untrained and 49.6% in the trained subjects.

Table V shows that the Q-BU percentage of the R-R interval at the onset of recovery is increased over the resting value and continues to increase before levelling off between 8-10 minutes recovery. The resting value in the untrained is 20.1 per cent and in the trained 18.2 per cent. In the untrained, the recovery values increase from 25.9 per cent to 29.6 per cent compared to 23.5 to 27.9 per cent in the trained subjects.

Figure 18 shows the relationship between the BUT, DFT and reduced

TABLE V

AVERAGE BRACHIAL UPSTROKE TIME, DIASTOLIC FILLING TIME AND Q-BRACHIAL UPSTROKE INTERVAL AS A PERCENTAGE OF THE R-R INTERVAL FOR 6 OARSMEN BEFORE (T_1,T_2) AND AFTER (T_3,T_4) TRAINING, AT REST R, AND IMMEDIATE R_1, 5 MINUTE R_2, AND 10 MINUTE R_3, RECOVERY FROM 5 MINUTE TEST AS MEASURED FROM THE BRACHIAL PULSE WAVE

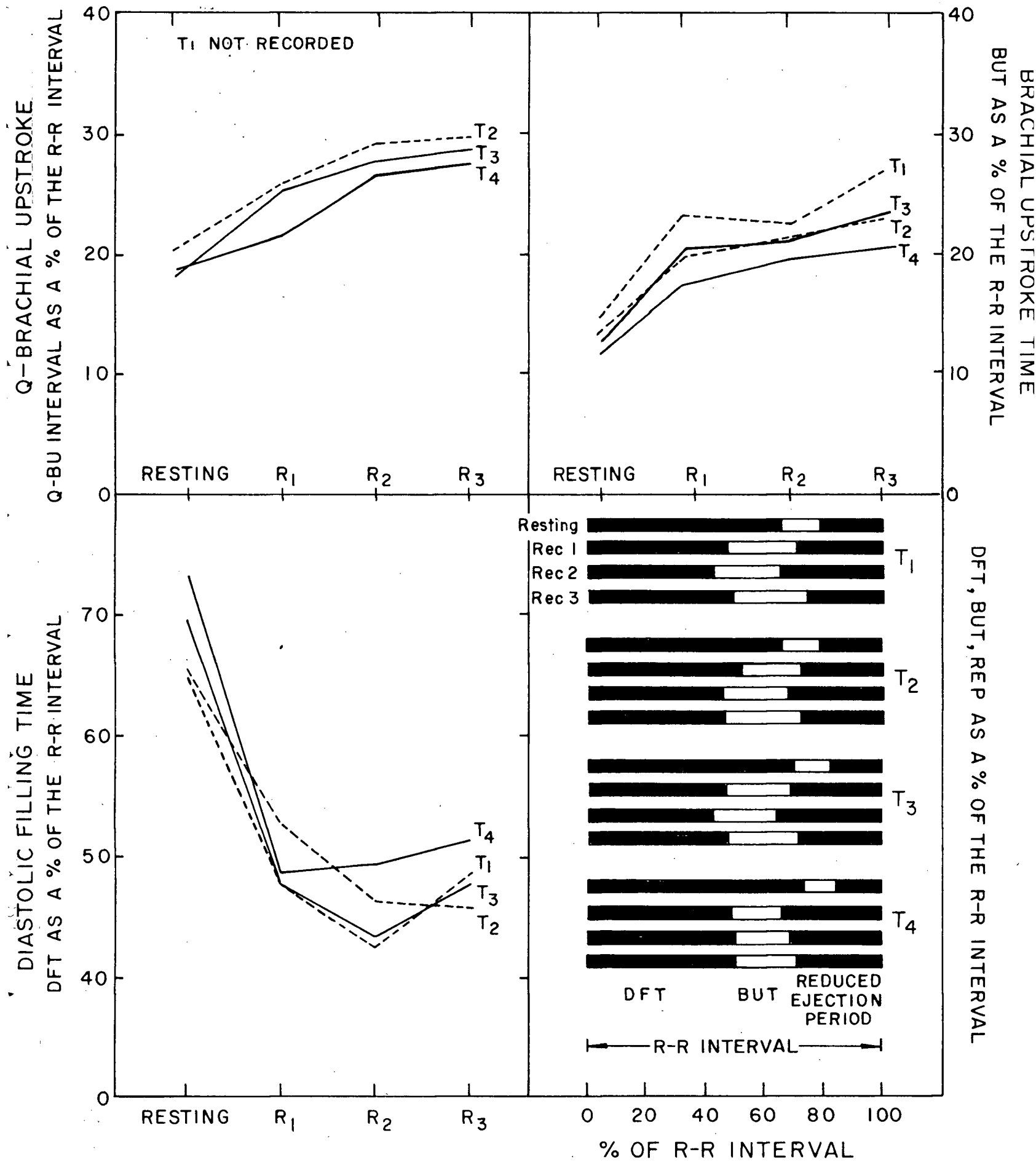
		T_1 %	T_2 %	Mean %	T_3 %	T_4 %	Mean %
Brachial Upstroke Time as a % of the R-R Interval	R	14.6	13.5	14.1 ± 1.7	12.8	11.6	12.2 ± 2.2
	R_1	23.1	19.8	21.5 ± 4.5	20.5	17.2	18.9 ± 4.0
	R_2	22.6	21.5	22.1 ± 2.8	21.2	19.3	20.3 ± 2.7
	R_3	26.9	23.0	25.0 ± 3.5	23.2	20.6	21.9 ± 3.9
Diastolic Filling Time as a % of the R-R Interval	R	64.6	65.6	65.1 ± 3.7	69.4	73.0	71.2 ± 4.2
	R_1	47.7	52.9	50.3 ± 7.1	47.7	48.8	48.3 ± 8.1
	R_2	42.6	46.3	44.5 ± 5.9	43.2	49.1	46.2 ± 8.1
	R_3	48.2	46.0	47.1 ± 2.7	47.9	51.2	49.6 ± 6.0
Q-BU Interval as a % of the R-R Interval	R		20.1	20.1 ± 3.1	18.1	18.3	18.2 ± 2.8
	R_1		25.9	25.9 ± 2.7	25.5	21.4	23.5 ± 1.6
	R_2		29.0	29.0 ± 4.41	27.8	26.5	27.2 ± 4.2
	R_3		29.6	29.6 ± 2.9	28.6	27.2	27.9 ± 2.8

TABLE VI

AVERAGE BRACHIAL UPSTROKE TIME, DIASTOLIC FILLING TIME AND REDUCED EJECTION PERIOD AS A PERCENTAGE OF THE R-R INTERVAL FOR SIX OARSMEN BEFORE (T_1,T_2) AND AFTER (T_3,T_4) TRAINING AT REST R, AND IMMEDIATE R_1, 5 MINUTE R_2, AND 10 MINUTE R_3 RECOVERY FROM 5 MINUTE STEP TEST

	Diastolic Filling Time		Brachial Upstroke Time		Reduced Ejection Period	
	T_1 % T_2	T_3 % T_4	T_1 % T_2	T_3 % T_4	T_1 % T_2	T_3 % T_4
R	65.1 ± 3.7	71.2 ± 4.2	14.1 ± 1.7	12.2 ± 2.2	20.8 ± 3.1	16.6 ± 2.5
R_1	50.3 ± 7.1	48.3 ± 8.1	21.5 ± 4.5	18.9 ± 4.0	28.2 ± 6.7	32.8 ± 7.9
R_2	44.5 ± 5.9	46.2 ± 8.1	22.1 ± 2.8	20.3 ± 2.7	33.4 ± 6.1	33.5 ± 7.8
R_3	47.1 ± 2.7	49.6 ± 6.0	25.0 ± 3.5	21.9 ± 3.9	27.9 ± 2.9	28.5 ± 4.3

Figure 18 The diastolic filling time, brachial upstroke time, reduced ejection period and Q-upstroke interval expressed as a percentage of the R-R interval.


Q-BRACHIAL UPSTROKE
Q-BU INTERVAL AS A % OF THE R-R INTERVAL
T1 NOT RECORDED
T2
T3
T4
RESTING
R1
R2
R3
BRACHIAL UPSTROKE TIME
BUT AS A % OF THE R-R INTERVAL
T1
T3
T2
T4
DIASTOLIC FILLING TIME
DFT AS A % OF THE R-R INTERVAL
DFT, BUT, REP AS A % OF THE R-R INTERVAL
Resting
Rec 1
Rec 2
Rec 3
DFT
BUT
REDUCED EJECTION PERIOD
R-R INTERVAL
% OF R-R INTERVAL

ejection period (REP) as components of the R-R interval before and after training during rest and recovery from exercise. Within the first five minutes of recovery the BUT percentage of the R-R interval remains fairly constant, the DFT percentage decreases and the REP percentage increases. By ten minutes recovery, the DFT percentage increases and the REP percentage decreases towards their respective resting values. The reduced ejection period does not seem to be regularly affected by training (Table VI, Figure 18).

The phase plane loop expresses the relationship between the rate of change of pulse pressure $\dot{p}$ and the pulse pressure P. The range between the minimum and maximum pulse pressure is designated as Pr. The range between the maximum positive ($+\dot{p}$) and negative ($-\dot{p}$) rates of change of pulse pressure is designated $\dot{P}r$. Table VII shows that the ratio of the pulse pressure range Pr to the rate of change of pulse pressure range $\dot{P}r$ varies very little between corresponding pre- and post-training values. Exercise tends to decrease the pre- and post-training ratios towards unity and recovery tends to return the ratios to the resting values. Table VII shows that training increases the positive ($+\dot{p}$) in relation to the negative ($-\dot{p}$) rate of change of pulse pressure for both the resting and recovery values. Exercise tends to decrease $+\dot{p}$ in relation to $-\dot{p}$ but recovery tends to return their relationship to the resting value.

Quantitative Interpretation of Changes in Strength, Muscular Endurance and Stamina

The determination and measurement of the improved cardiovascular efficiency resulting from training is relatively dependent on the indirect methods used in this study. The stamina and muscular endurance tests

TABLE VII

AVERAGE RATIO BETWEEN THE PULSE PRESSURE RANGE Pr AND THE RATE OF CHANGE OF PULSE PRESSURE $\dot{Pr}$, AND THE AVERAGE RATIO BETWEEN THE POSITIVE $+\dot{p}$ AND NEGATIVE $-\dot{p}$ RATES OF CHANGE OF PRESSURE, FOR SIX OARSMEN, BEFORE (T_1,T_2) AND AFTER (T_3,T_4) TRAINING, AT REST R, AND IMMEDIATE REST R_1, 5 MINUTE R_2, AND 10 R_3 RECOVERY FROM A 5 MINUTE STEP TEST, AS MEASURED FROM THE PHASE PLANE LOOP

		T_1	T_2	Mean T_1 T_2	T_3	T_4	Mean T_3 T_4
$Pr/\dot{Pr}$	R	1.62	1.63	1.63 ∓ 0.17	1.61	1.60	1.61 ∓ 0.13
	R_1	1.14	1.09	1.12 ∓ 0.16	1.18	1.08	1.13 ∓ 0.09
	R_2	1.27	1.27	1.27 ∓ 0.16	1.35	1.32	1.34 ∓ 0.12
	R_3	1.39	1.37	1.38 ∓ 0.15	1.40	1.40	1.40 ∓ 0.10
$+\dot{p}/-\dot{p}$	R	3.34	2.95	3.15 ∓ 0.81	3.92	3.95	3.94 ∓ 0.71
	R_1	2.86	2.80	2.83 ∓ 0.67	3.38	3.25	3.32 ∓ 0.91
	R_2	2.85	2.79	2.83 ∓ 0.68	2.74	2.96	2.82 ∓ 0.48
	R_3	2.77	2.40	2.59 ∓ 0.68	2.63	3.13	2.88 ∓ 0.56

performed offer more direct and perhaps equally valuable indications of the improved cardiovascular efficiency of the body. These coupled with the strength tests on the oarsmen offer a fairly comprehensive evaluation of the subjects' functional capacity before and after training.

Figure 19 indicates that back extensor strength improved with training for all individuals except G.H. Left and right grip strength increased with training in some individuals and decreased in others. Leg extensor strength improved an average of 264.5 lbs. with training, from a group average of 922.8 $\pm$ 89 lbs. before training to 1187.3 $\pm$ 106 lbs. after training. Individual leg strength improvement is given in Table VIII.

All individuals except M.W. improved their mile run time with training (Figure 20). The group average before training was five minutes thirty seconds compared to five minutes twenty-five seconds after training.

The muscular endurance and strength of the major muscle areas of the body improved considerably with circuit and weight training (Figure 19). By the end of training, each individual could perform greater work tasks in less time. Approximately 4000 lbs. more per person per circuit workout (10-15 min) was added to the load while the work time decreased 3-5 minutes.

Determination of Significance of Difference Between Pre- and Post-Training Data

A total of 42 t-tests were performed to compare 42 cardiovascular variables to determine if significant differences occurred between pre- and post-training values. The variables tested were resting, maximum and recovery oxygen consumption, heart rate at maximum oxygen

TABLE VIII

LEG EXTENSOR STRENGTH IN 6 OARSMEN* BEFORE TRAINING AND AFTER TWO MONTHS OF THREE TIMES PER WEEK TRAINING ON AN ECCENTRIC ERGOMETER. TRAINING CONSISTED OF THREE SETS OF THREE REPETITIONS INVOLVING DYNAMIC CONCENTRIC TRAINING AT 720 LBS FOLLOWED IMMEDIATELY BY DYNAMIC ECCENTRIC CONTRACTIONS OF 2000 - 2500 LBS (AFTER BANISTER, 1966) (2).

Subject	Pre-training lbs	Post-training lbs
RJ	959 ± 101	1342 ± 80
DS	1033 ± 59	1161 ± 63
RF	686 ± 133	983 ± 51
MW	920 ± 95	1213 ± 173
BS	1065 ± 93	1322 ± 115
GH	926 ± 52	1104 ± 154

*mean of 6 determinations

Figure 19 Changes in back, leg and grip strength of six oarsmen as a result of eight weeks of circuit and weight training.

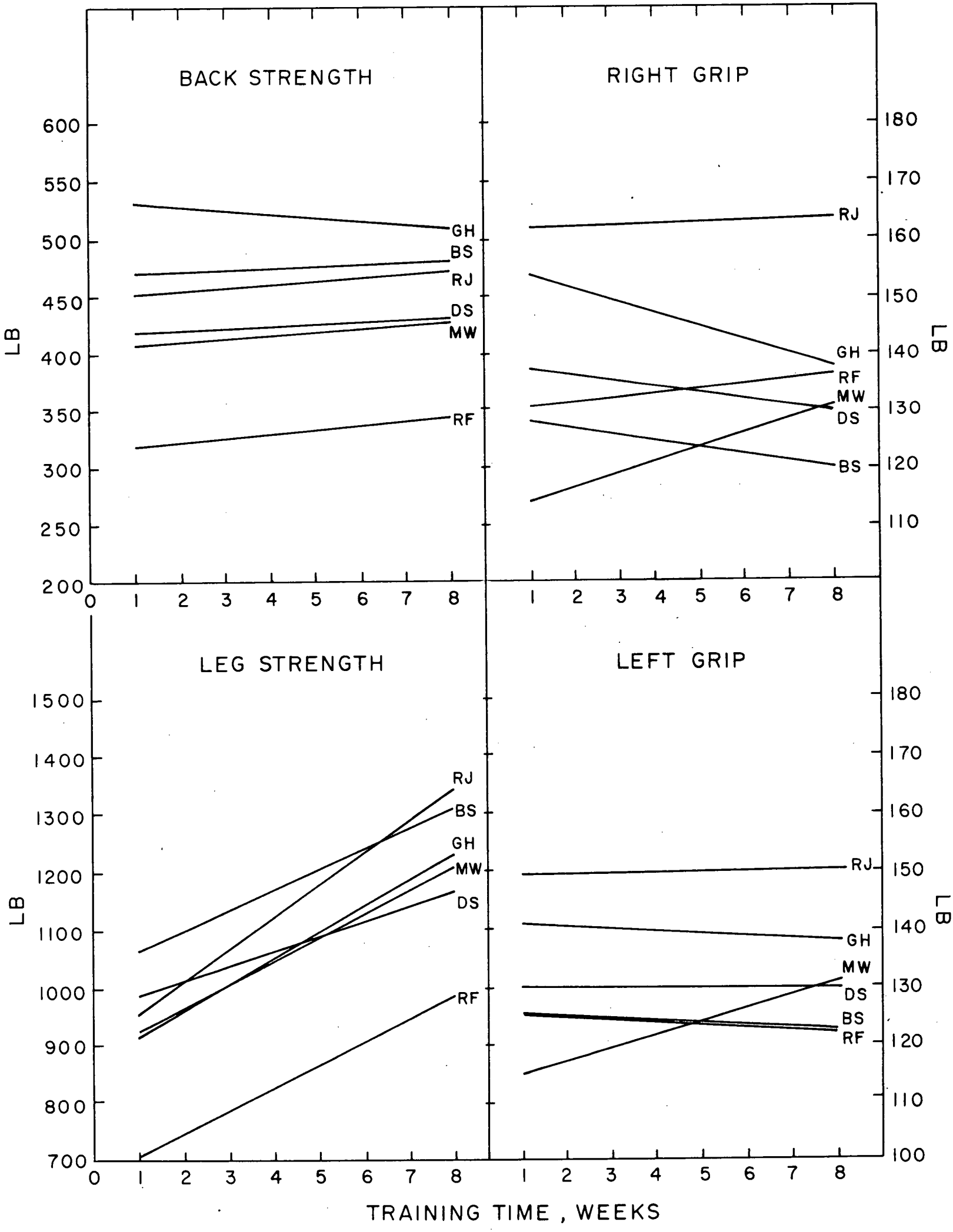
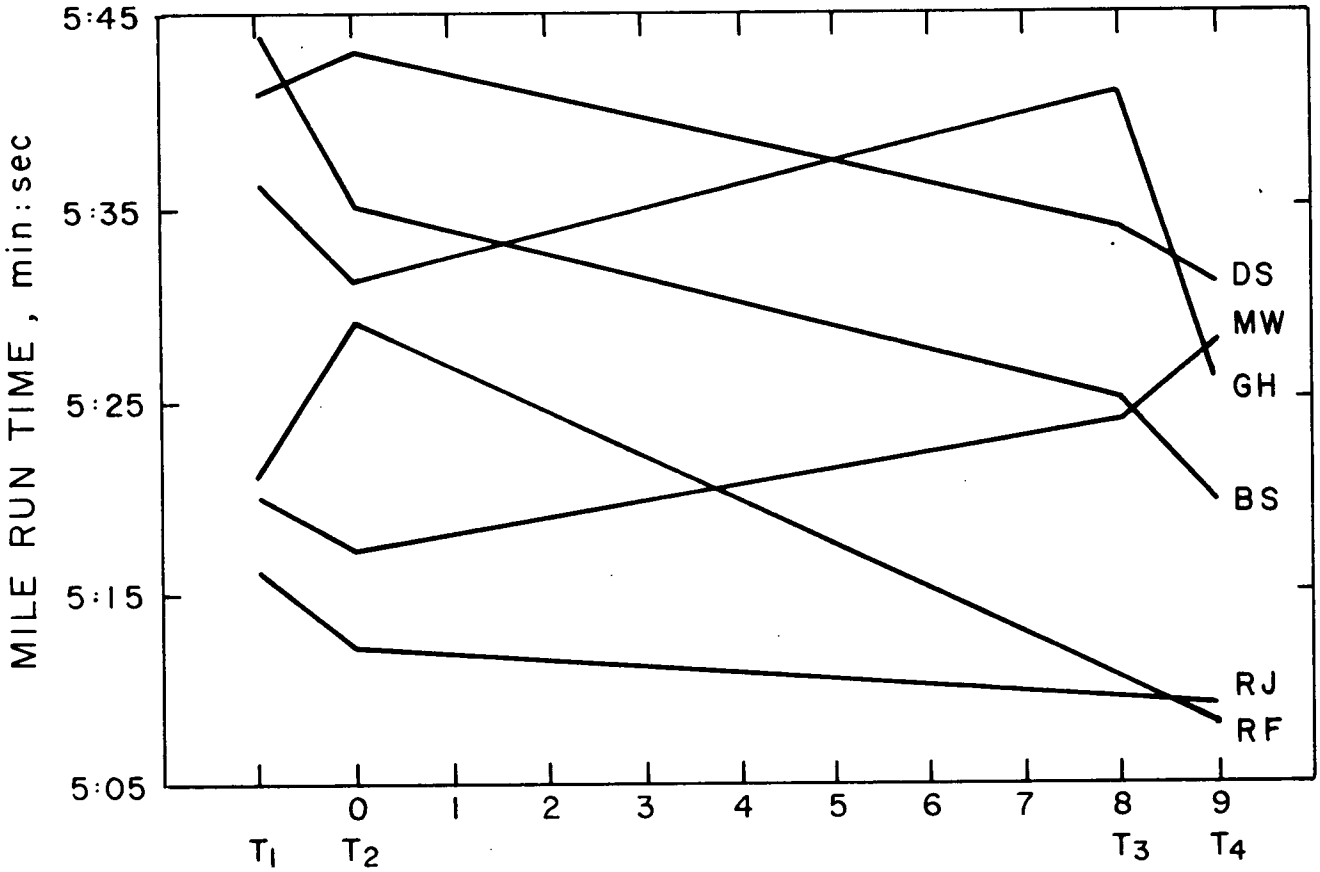
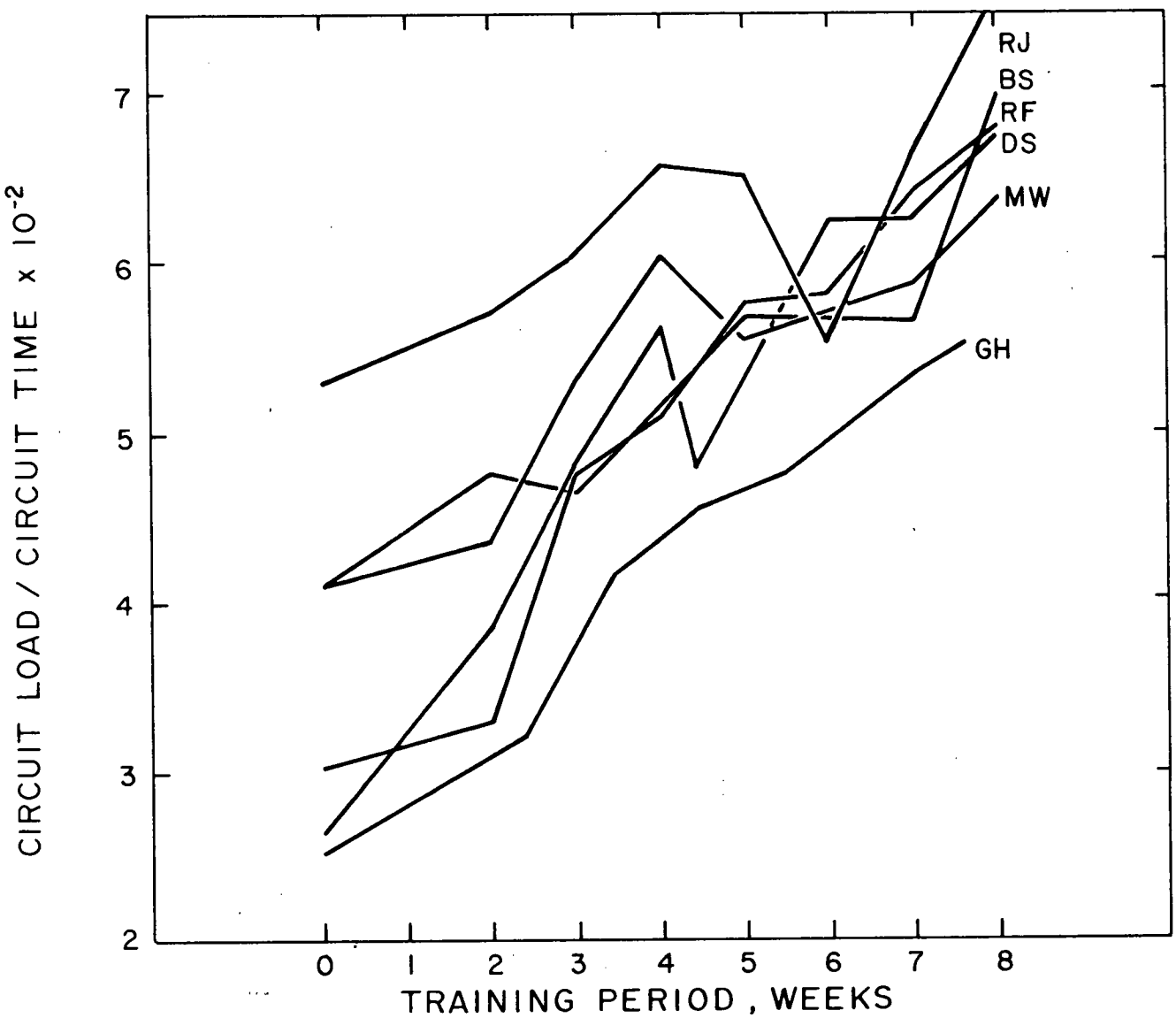

BACK STRENGTH
RIGHT GRIP
LEG STRENGTH
LEFT GRIP
LB
GH
BS
RJ
DS
MW
RF
TRAINING TIME , WEEKS

Figure 20 The effects of eight weeks of circuit training and sustained running on the ratio circuit load/circuit time and on the mile run time of six oarsmen.


MILE RUN TIME, min:sec
5:45
5:35
5:25
5:15
5:05
DS
MW
GH
BS
RJ
RF
0
1
2
3
4
5
6
7
8
9
T1
T2
T3
T4


CIRCUIT LOAD / CIRCUIT TIME x 10-2
7
6
5
4
3
2
RJ
BS
RF
DS
MW
GH
0
1
2
3
4
5
6
7
8
TRAINING PERIOD, WEEKS

consumption and maximum heart rate during exhaustive exercise; BUT, DFT, REP, Q-BU interval during rest and immediate, five minute and ten minute recovery from exercise, these variables being compared as time intervals and as a percentage of the R-R interval; the ratios $+\dot{p}/-\dot{p}$ and $Pr/\dot{P}r$ during rest and immediate, five minute and ten minute recovery from exercise. The results indicate that only three variables changed significantly (.05 level) with training, these being the immediate recovery Q-BU interval expressed as a percentage of the R-R interval and the resting DFT expressed both as a percentage of the R-R interval and as a time interval.

REFERENCES

1. Starr, I., Ogawa, S., "A Clinical Study of the First Derivative of the Brachial Pulse", Am. Heart J., Vol. 65, 1962, pp. 482-94.

2. Banister, E.W., "Theories of Strength Training", Royal Canadian Legion Coaching Review, Legion House, Ottawa, Vol. 4, 2, September, 1966.

CHAPTER V

DISCUSSION

Oxygen Consumption

It appears that training increased the maximum oxygen consumption and decreased the heart rate at which it occurred. It is possible that an increased stroke volume and/or an increased A-V oxygen difference could be responsible for the increased consumption. The slower ride times after training might be explained by the nature of the conditioning programme - each circuit workout challenged the subject to push himself to exhaustion. No opportunity to recover from the eight weeks of training was given to the subjects when T_3 was administered and they perhaps were too physically and mentally tired to work to their former limit. Low recovery oxygen consumption during T_3 appears to support this interpretation.

The relatively high oxygen consumption (l/min) obtained on the oarsmen, particularly the post-training values, compare favorably with values obtained on athletes measured by Astrand (1), Dill and Robinson (2) and Christiansen and Hoberg (3). However, when body size is considered, the values for maximum consumption are less than Astrand's values for world class 1500 meter runners and cross country skiers (Table I) - the oarsmen mean being 52.90 ∓ 7.35 ml/kg/min compared to a mean of 76.8 ∓ 8.1 ml/kg/min for the skiers and runners. The maximum consumption values for the oarsmen expressed in ml/kg/min are larger than values by Mitchell (4), Astrand (5) and Anderson (6) for healthy students and soldiers the same age.

Many values in excess of 5 l/min were determined on the oarsmen,

usually during the second last minute of the exhaustive ride. However, because of the variability of individual values when calculations were made over a one minute interval, it was necessary to express maximum oxygen consumption as an average consumption over the last three minutes of exercise. This procedure offered more reliability but modified the large consumption values obtained on most of the oarsmen.

The lack of significant differences between pre- and post-training oxygen consumption might reflect the relatively high level of fitness of the athletes before the training commenced. As well, the training programme was designed primarily to improve the strength and endurance of skeletal muscle and secondarily to improve the efficiency of cardiac muscle.

Electrocardiogram

The $\measuredangle$ RS and T-wave values and patterns did not indicate changes in fitness for this group of athletes training for eight weeks. A consistent pattern of T-wave amplitude change was noted for these oarsmen during exercise and recovery but the pattern and amplitudes might be better evaluated if compared to those of less fit individuals. The $\measuredangle$ RS values after training tended to be larger than before training but the differences were small and exceptions did exist both of which tended to decrease the power of the RS amplitude to distinguish changes in fitness. The established parameter of heart rate clearly indicated that improvement in cardiovascular efficiency did occur with training.

The T-wave has been labelled as the least stable part of the ventricular complex, being influenced by several factors including ischemia, emotion, hyperventilation and temperature (7). High T-waves

may be due to ischemia, hyperkalemia or autonomic imbalance. Kilburn (8) has indicated that exercise produces acidosis in muscle cells, that some potassium ions are exchanged for hydrogen ions and that both are released from striated muscle to the extracellular fluid. These ions could find their way to cardiac muscle via the blood stream. Rose, Dunn, and Bargen (9) also support this contention. It is probably valid to assume that hyperkalemia did exist in the oarsmen during and after exercise, at least for two to three minutes (9,10). Low or negative T-waves have been related to ischemia, myocardial hypertrophy and electrolytic disturbances. The pattern of T-wave amplitude change during exercise and recovery is unexplained. Perhaps the dominant peak of the T-wave pattern which begins to form towards the end of exercise and which peaks early in recovery reflects the buildup of serum potassium and/or ischemia resulting from skeletal muscle activity. The decrease in T-wave amplitude following the peak to or below the resting level might reflect the effects of homeostatic mechanisms returning the internal environment to its resting situation.

Low voltage of the RS may express to the clinician diffuse myocardial damage. Electrolytic imbalance such as high levels of serum potassium may short ciruit the cardiac currents by creating an abnormal conducting fluid medium (11).

Pulse Wave

The contrasting features between resting and recovery pulse wave forms are essentially those shown also between pre- and post-training recovery pulse wave forms. In short, after a given exercise, the untrained individual's recovery pulse deviates more from the resting pulse than does the trained individual's. Thus, it is possible, perhaps

even probable, that after a given exercise the degree of distortion of the recovery wave from the resting wave directly reflects the degree of fitness of the subject, the greater the distortion the less fit the individual. The recovery pulse, compared to the resting pulse, has a reduced or absent tidal wave, a long catacrotic descent to a low dicrotic wave and rounded primary and dicrotic waves often with reduced amplitudes. Wiggers (12) has noticed waves with similar characteristics to be due to low arterial resistance. Resistance is determined by passive factors such as the equilibrium between intra- and extra-vascular pressures and the resistance offered by venous pressure distal to capillaries, and by active factors such as changes in the calibre of the arterioles produced by vasomotor action (13). Dilated vessels are a common occurrence during and after vigorous exercise. The return to the resting pulse form as recovery proceeds might result from the lessening of the dilation of the vessels causing a more rigid system and resulting in a wave similar to the resting wave, characterized by a rapid ascent to a large peak, a high incisura and a gradual decline during diastole.

The ratio $+\dot{p}/-\dot{p}$ was seen to increase with training. It seems logical that an increased rate of change of pressure during initial ejection, even in the resting state, is indicative of improved cardiovascular efficiency. However, it is important to remember that the brachial pulse wave is not an exact indicator of pressure changes in the left ventricle during systole and diastole. The ventricular pressure wave, as measured from peripheral arteries, undergoes modifications in form due to damping of the finer oscillations of the fundamental wave by the distensible arterial walls, and by the reflection of a diphasic

wave from the periphery which summates with the fundamental wave. Nevertheless, it is possible that an increased rate of change of pressure occurring from ventricular ejection would be accurately represented in the periphery as an increased rate of change of pulse wave amplitude during upstroke.

Each ventricular systole forces blood into an already filled and stretched aorta, partly by moving the existing volume peripherally, and partly by further distension of the aorta and its branches. Assuming a normal state of arterial distensibility, pulse pressure increases as a result of augmented stroke volume. It is probable, that with proper training, stroke volume is increased, even in the resting state because of greater filling of the ventricles during diastole, a prolongation of the ejection period and, occasionally, even by more complete emptying (14). This study indicates that the brachial upstroke time remained the same in the trained and untrained states. Thus, if the "trained" heart released a greater stroke volume, then the rate of change of pulse pressure during ejection would be increased for the "trained" individual. For this to occur either the heart would have to generate greater force to impart increased momentum to the ventricular blood, or the peripheral resistance would have to be less. One would expect the heart to become more powerful with training. The vigor and pattern of ventricular contraction and consequently its systolic discharge can be influenced by agents which primarily affect the contractility of the myocardium as well as by those which secondarily affect contractility through changes in initial tension or length such as are induced by alteration in venous return, atrial resistance and heart rate (15). Research by Starling and

Wiggers has led to the suggestion that the "law of the heart is the same as the law of muscular tissue generally, that the energy of contraction, however measured, is a function of the length of the muscle fiber under equivalent states of responsiveness". (16)

REFERENCES

1. Astrand, P-O., "Human Physical Fitness with Special Reference to Age and Sex", Physiological Reviews, Vol. 36, 1956, p. 314.

2. Robinson, S., Edwards, H.T., Dill, D.B., "New Records in Human Powers", Science, Vol. 85, 1937, pp. 409-10.

3. Christiansen, E.H., Hoberg, "Physiology of Skiing", Berichte uber die Gres. Physiol., Vol. 146, 1951, p. 229.

4. Mitchell, J.H., Sproule, B.J., Chapman, C.B., "The Physiological Meaning of the Maximal Oxygen Intake Test", J. of Clinical Investigation, Vol. 37, 1958, p. 538.

5. Astrand, op. cit., p. 309.

6. Anderson, K.L., Nord med., Vol. 54, 1955, pp. 1246-48.

7. Turner, R.W.D., Electrocardiography, 2nd ed., E. and S. Livingstone Ltd., Edinborough and London, 1964, p. 66.

8. Kilburn, K.H., "Muscular Origin of Elevated Plasma Potassium During Exercise", J. of Appl. Physiology, Vol. 21, (2), 1966, pp. 675-78.

9. Rose, K.D., Dunn, F.L., Bargen, D., "Serum Electrolyte Relationship to Electrocardiographic Change in Exercising Athletes", J. of Am. Med. Assoc., Jan. 1966, Vol. 195, pp. 111-14.

10. Kilburn, K.H., "Movement of Potassium During Acute Respiratory Acidosis and Recovery", J. of Applied Physiology, Vol. 21, (2), 1965, pp. 679-84.

11. Lipman, B.S., Massu, E., Clinical Unipolar Electrocardiography, The Year Book Publishers Inc., Chicago, 1951, p. 139.

12. Wiggers, C.J., Circulatory Dynamics, Grune and Stratton, New York, 1952, p. 20.

13. Ibid., pp. 24-25.

14. Ibid., p. 42.

15. Ibid., p. 47.

16. Ibid., p. 48.

CHAPTER VI

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

The study had three purposes; first, to appraise the cardiovascular fitness of six world class oarsmen by analysis of their oxygen consumption, heart rate, dynamics of arterial blood flow and various parameters measured from the electrocardiogram; secondly, to explore relatively new techniques for studying and measuring the externally recorded brachial pulse wave, its first derivative and the phase plane relationship of this derivative with the original pulse wave; and lastly, to determine the effectiveness of a conditioning programme designed to improve the cardiovascular efficiency, muscular endurance, strength and stamina of these oarsmen.

The experimental design allowed each of the six subjects to be tested twice before and twice after an eight week conditioning programme. Each test battery included a maximum bicycle ergometer ride to exhaustion, a submaximal five minute step test, a mile run for time, dynamometer strength tests and a muscular endurance test. The conditioning programme consisted of circuit training, strength training and endurance running, there being five workouts in each seven day period.

Conclusions

The main conclusions are outlined below:

1. The values of maximum oxygen consumption recorded for these oarsmen are similar to the high values recorded on other champion endurance athletes and are higher than values recorded on healthy students

and soldiers the same age (see Discussion).

2. No significant changes occurred between pre- and post-training T-wave and $\measuredangle$ RS amplitudes. A regular pattern of T-wave change during exercise and recovery from exercise was suggested by the data.

3. The value of the pulse wave, its first derivative and the phase plane loop to indicate changes in fitness has not been fully determined. Small differences in the primary wave and first derivative from those described by other investigators were seen. Several measurements from the pulse wave, the derivative and the loop did show that fitness changes occurred with training (see below), but the importance of these parameters has not been fully determined. No information on the effect that exercise has on the pulse wave form could be found in the literature. It appears that the pulse wave form during recovery from a known quantity and type of exercise might be a reliable indicator of the degree of fitness of a subject.

4. The conditioning programme improved the leg and back static strength and the endurance of all the major muscle groups of the body. Though only 3 of 42 cardiovascular variables tested showed significant differences (.05 level) between pre- and post-training data, most variables indicated improved efficiency with training. It is concluded that (a) the cardiovascular variables studied could not differentiate between the high pre-training fitness of the athletes and their fitness after training and/or (b) that the strength and muscular endurance of these athletes improved more dramatically than did the cardiovascular fitness.

5. The parameters which indicated, to some degree, the

improvement in cardiovascular efficiency are: maximum oxygen consumption, heart rate, resting DFT expressed both as a temporal value and as a percentage of the R-R interval, resting BUT percentage of the R-R interval, resting and recovery values of the Q-BU interval, $+\dot{p}/-\dot{p}$, mile run time, circuit time.

6. The parameters which did not clearly indicate that improved cardiovascular efficiency occurred are: resting oxygen consumption, maximal bicycle ergometer ride time, T-wave amplitude, $\lessgtr$ RS amplitude, recovery value of DFT, recovery value BUT, $Pr/\dot{P}r$ during rest and recovery.

Recommendations

1. The post-exercise pulse waves (and their derivatives) might prove reliable indicators of cardiovascular efficiency if viewed throughout recovery until the resting pattern returns. The time for return to the normal pattern, the appearance of the tidal wave and the position of the dicrotic notch and wave might be discriminatory features in determining levels of fitness.

2. Studies should be performed to determine whether the pattern of T-wave amplitude change during and following exercise and the time for its return to the resting amplitude might prove to be discriminatory features in determining levels of fitness.

3. The method used for analyzing respiratory gas over short intervals (one minute) proved to be inadequate. The measurement of carbon dioxide production was attempted but abandoned because of its unreliability. It is suggested that the respiratory gas be analyzed by apparatus such as a Scholander gas analyzer.

4. Other investigators have suggested that a test designed to elicit maximum oxygen consumption should exhaust the subject within five minutes. Partly as a result of the present study, it is felt that five minutes of maximum exercise might not be sufficient time to elicit full cardiovascular response to intensive exercise.

5. If the unestablished cardiovascular variables studied here are to be studied in the future, it is suggested that any training be specifically directed to improving cardiovascular fitness and that the intensity of training and the subjects be such that significant cardiovascular improvement will result. In this way, a more accurate estimation can be made of the value of these unestablished cardiovascular variables as indicators of levels of fitness.

BIBLIOGRAPHY

A. BOOKS

Brouha, L., "Training", Science and Medicine of Exercise and Sports, Harper Bros. Publishers, New York, 1960, pp. 409-10.

Consalazio, F.C., Johnson, R.E., Pecora, L.J., Physiological Measurements of Metabolic Functions in Man, McGraw-Hill Inc., Toronto, 1963, p. 341.

Cureton, T.K., Physical Fitness of Champion Athletes, University of Illinois Press, Urbana, 1951, pp. 137-62.

Fleishman, E.A., The Structure and Measurement of Physical Fitness, Prentice-Hall Inc., N.J., 1964, pp. 130-31.

Lipman, B.S., Massu, E., Clinical Unipolar Electrocardiography, The Year Book Publishers Inc., Chicago, 1951, p. 139.

Matthews, D.K., Measurement in Physical Education, W.B. Saunders Co., Philadelphia and London, 1963, pp. 65-68.

McDonald, D.A., Blood Flow in Arteries, London, Edward Arnold, 1960, p. 201.

Morgan, R.E., Adamson, G., Circuit Training, 1961, pp. 21-22, p.31.

Rushmer, R.F., Cardiovascular Dynamics, 2nd Ed., W.B. Saunders Co., Philadelphia and London, 1961, pp. 238-96, pp. 38-43.

Scher, A.M., "Excitation of the Heart", Handbook of Physiology, Section 2, Circulation, Vol. 1, Washington, D.C., 1962, pp. 323-26.

Taylor, H.L., "Exercise and Metabolism", Science and Medicine of Exercise and Sports, Harper Bros., New York, 1960, p. 144.

Turner, R.W.D., Electrocardiography, 2nd Ed., E. and S. Livingstone Ltd., Edinborough and London, 1964, p. 66.

Wiggers, C.J. Circulatory Dynamics, Grune and Stratton, New York, 1952, p. 20.

B. PERIODICALS

Andersen, K.L., Nord. med., Vol. 54, 1955, pp. 1246-48.

Astrand, P-O., "Human Physical Fitness with Special Reference to Age and Sex", Physiological Reviews, Vol. 36, 1956, p. 327.

Bobskii, E.B., Karpman, V.L., Petrov, G.M., Sachkova, A.I., "Use of an Electronic Differentiating Device in Physiological Studies", Biophysics, Vol. 4, 1959, p. 102.

Balke, B., Ware, C.W., "An Experimental Study of Physical Fitness of Air Force Personnel", U.S. Armed Forces Medical Journal, Vol. 10, June, 1959, pp. 675-88.

Banister, E.W., Cureton, T.K., Abbott, B.C., Pollard, J.W., "A Comparative Study of the Brachial Pulse Wave and Its Time Derivatives Among Athletic, Normal, and Pathological Subjects", Journal of Sports Medicine and Physical Fitness, Vol. 6, No. 2, June, 1966, pp. 92-99.

Banister, E.W., "Theories of Strength Training", Royal Canadian Legion Coaching Review, Legion House, Ottawa, Vol. 4,2, September, 1966.

Banister, E.W., "Physiological Principles Applied to a New Method of Strength Training", Unpublished, The University of British Columbia, 1966.

Brouha, L., Gallagher, "A Simple Method of Testing Physical Fitness in Boys", Research Quarterly, Vol. 14, 1943, pp. 23-30.

Brouha, L., Heath, C.W., New England Journal of Medicine, Vol. 228, 1933, p. 473.

Brown, S.R., Banister, E.W., Dower, G.E., "Time Derivatives of the Corotid Pulse Wave and Phase Plane Analysis of Cardiovascular Condition", presented at C.A.H.P.E.R. Convention, Fredericton, N.B., June, 1965.

Buskirk, E., Taylor, H.L., "Maximum Oxygen Uptake and Its Relation to Body Composition with Specific Reference to Chronic Physical Activity and Obesity", Journal of Applied Physiology, Vol. 11, 1957, p. 72.

Carlisle, F., Carlisle, U., "T-wave Changes in Strenuous Exercise", Track Technique, No. 2, Dec., 1960.

Christiansen, E.H., "Beitrage zur Physiologie Schwerer Korperlicher Arbeit", VII, Mitteilung: Uber die Brauchborkeit der Acetylenmethod Arbeit: Arbeitsphysiologie, 1932, pp. 479-88.

Christiansen, E.H., Hoberg, "Physiology of Skiing", Berichte uber die Gres. Physiologie, Vol. 146, 1951, p. 229.

Cooper, E.L., O'Sullivan, J., Hughes, E., "Athletics and the Heart, An Electrocardiographic and Radiological Study of the Response of the Healthy and Diseased Heart to Exercise", Medical Journal Australia, Vol. 1, 1937, pp. 569-79.

Dontas, A.S., Cottas, C.S.,"Comparison of Simultaneously Recorded Inter-Arterial and Extra-Arterial Pressure Pulses in Man", American Heart Journal, Vol. 59, 1960, p. 576.

Gerschler, W., "Training for Middle and Long Distance Running", Track Technique, Vol. 17, Sept. 1964, p. 530.

Gleason, W.L., Braunwald, E., "Studies on the First Derivative of the Ventricular Pressure Pulse in Man", Journal of Clinical Investigation, Vol. 41, 1962, pp. 80-91.

Harrison, T.R., Dixon, K., Russell, R.O., Bidway, P.S., Coleman, H.N., "The Relation of Age to the Duration of Contraction, Ejection and Relaxation of the Normal Human Heart", American Heart Journal, Feb. 1964, pp. 189-99.

Hettinger, Muller, "Muskellustung und Muskreltraining", Arbeitsphysiologie, Vol. 15, 1953, pp. 111-16.

Hill, A.V., Lupton, H. "Muscular Exercise, Lactic Acid and the Supply and Utilization of Oxygen", Quart. Journal of Medicine, Vol. 16, 1923, pp. 135-71.

Hoogerwerf, S., "Elektrokardiographische untersuchungen der Amsterdamer Olympiadekampfer", Arbeitsphysiologie, Vol. 2, 1929, pp. 61-76.

Hunt, E.A., "Electrocardiographic Study of Twelve Champion Swimmers Before and After 110 Yard Sprint Swimming Competition", Canadian Medical Association Journal, Vol. 88, 1963, pp. 1251-53.

Hyman, G., Winsor, T., "What Can Be Found in Arterial Pulse Waves", American Heart Journal, Vol. 61, 1961, pp. 424-26.

Kilburn, K.H., "Movement of Potassium During Acute Respiratory Acidosis and Recovery", Journal of Applied Physiology, Vol. 21 (2), 1965, pp. 679-84.

Kilburn, K.H., "Muscular Origin of Elevated Plasma Potassium During Exercise", Journal of Applied Physiology, Vol. 21 (2), 1966, pp. 675-78.

Kipping, H.W., Deutsche med Wehnschr, Vol. 63, 1937, p. 462.

LeBlanc, J.A., "Use of Heart Rate as an Index of Work Output", Journal of Applied Physiology, Vol. 10, 1957, pp. 275-80.

Lewis, B.M. Morton, J.W., Journal of Applied Physiology, Vol. 7, 1954, p. 309.

McDonald, D.A., Taylor, M.G., "Hydrodynamics of the Arterial System", Prog. Biophysics, Vol. 9, 1959, p. 105.

Mitchell, J.H., Sproule, B.J., Chapman, C.B., "The Physiological Meaning of the Maximal Oxygen Intake Test", Journal of Clinical Investigation, Vol. 37, 1958, p. 538.

Neal, N.J., Halpern, W., Reeves, T.J., "Velocity and Acceleration Pressure Changes in Heart and Arteries", Journal of Applied Physiology, Vol. 15, 1960, pp. 747-49.

Remington, J.W., Wood, E.N., "Formation of the Peripheral Pulse Contour in Man", Journal of Applied Physiology, Vol. 10, 1956-57, p.433.

Robinson, B., "The Corotid Pulse I: Diagnosis of Aortic Stenosis by External Recordings", British Heart Journal, Vol. 25, 1963, pp. 51-60.

Robinson, S., Edwards, H.T., Dill, D.B.,"New Records in Human Power", Science, Vol. 85, 1937, pp. 409-10.

Rose, K.D., Dunn, P.L., "Physiology of Running Studied by Use of Radiotelemetry", The Journal of Sports Medicine and Physical Fitness, published after 1964.

Rose, K.D., Dunn, F.L., Bargen, D., "Serum Electrolyte Relationship to Electrocardiographic Change in Exercising Athletes", Journal of American Medical Association, Jan. 1966, Vol. 195, pp. 111-14.

Rushmer, R.F., "Initial Ventricular Impulse", Circulation, Vol. 29, 1962, p. 282.

Saltin, B., "Aerobic Work Capacity and Circulation at Exercise in Man", Acta Physiol. Scand., Vol. 62, supp. 230, 1964, p. 37.

Slonim, N.B., Gillespie, D.G., Harold, W.H., "Peak Oxygen Uptake of Healthy Young Men as Determined by a Treadmill Method", Journal of Applied Physiology, Vol. 10, 1957, p. 401.

Starr, I., Ogawa, S., "A Clinical Study of the First Derivative of the Brachial Pulse", American Heart Journal, Vol. 65, 1962, pp. 482-94.

Taylor, H.L., Buskirk, E., Henschel, A., "Maximum Oxygen Intake as an Objective Measure of Cardio-Respiratory Performance", Journal of Applied Physiology, Vol. 8, 1955, pp. 73-80.

Warren, J.V., Leonard, J., "Intravascular Pressure Recording", Methods in Medical Research, Vol. 7, Chicago, 1958, Year Book Publishers Inc.,

Weissler, A.M., Peeler, R.G., "Relation Between Left Ventricular Ejection Time, Stroke Volume and Heart Rate in Normals", American Heart Journal, Vol. 62, 1961, p. 367.

Wiggers, C.J., "Studies on the Consecutive Phases of the Cardiac Cycle", American Journal of Physiology, Vol. 56, 1921, p. 415.

Wolf, J.G., "Effect of Posture and Muscular Exercise in the Electrocardiogram", Research Quarterly, Vol. 24, No. 4, Dec. 1953, pp. 323-26.

Wyndham, C.H., Strydom, N.B., Maritz, J.S., Morrison, J.F., Peter, J., Potgieter, Z., "Maximum Oxygen Intake and Maximum Heart Rate During Strenuous Work", Journal of Applied Physiology, Vol. 14, 1959, pp. 927-36.

APPENDIX A

PROCEDURE FOR CALCULATION OF OXYGEN CONSUMPTION

Correction of chamber volume to STPD.

$V_{initial}$ = Chamber volume - (subject volume + volume of step)

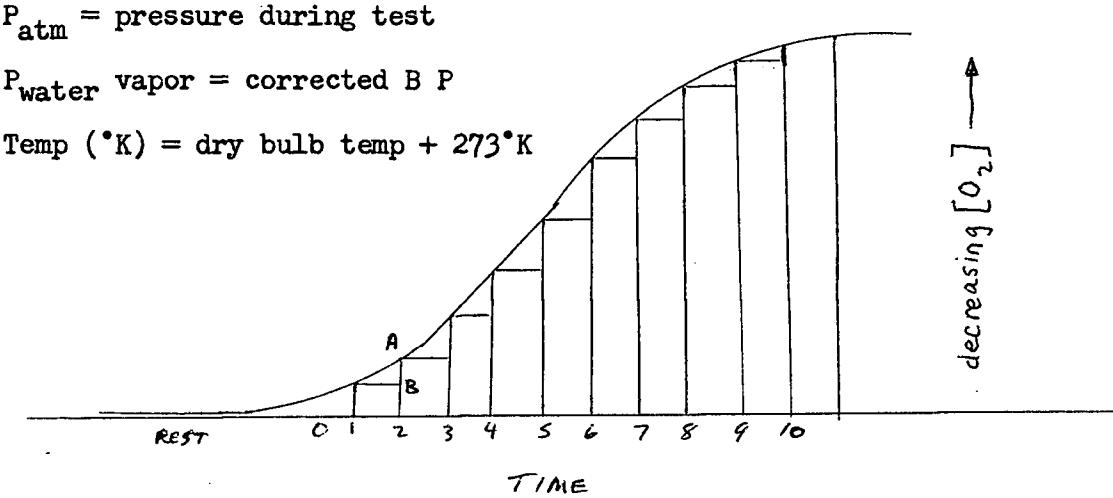
$$V_{corrected} = V_{initial} \times \frac{P_{atm} - P_{water\ vapor}}{760} \times \frac{273\ ^{\circ}K}{Temp\ (^{\circ}K)}$$

Conversion of linear distance to percentage oxygen consumed.

P_{atm} = pressure during test

P_{water} vapor = corrected B P

Temp (°K) = dry bulb temp + 273°K



Measure AB in mm with Vernier calipers

1 division represents .04% VO_2*

10 divisions = x mm

$$K = \frac{10}{x} \times .04\%\ VO_2$$

linear measure x K = % VO_2

% VO_2 x $V_{corrected}$ = VO_2 consumed

* VO_2 represents decrement in oxygen concentration.

APPENDIX B

CIRCUIT AND STRENGTH TRAINING PROGRAMME UTILIZED BY THE SIX OARSMEN DURING THEIR EIGHT WEEK OFF-WATER TRAINING. THE PROGRAMME WAS SPECIFICALLY DESIGNED FOR THEIR USE BY LLOYD PERCIVAL, DIRECTOR, THE FITNESS INSTITUTE, DON MILLS, ONTARIO.

WARM-UP:

All Over Stretch
15 times.

Stomach Pumping (seated)
2x15 reps.

Half Squats
2x20 reps.

Jiggle Bounce
2x60 secs.

DO EACH OF THE EXERCISES IN YOUR CIRCUIT 3 TIMES AT MODERATE PACE

Rest 2-3 minutes.

CIRCUIT

NOTE: Each exercise is to be done until the full number of repetitions has been achieved before the next exercise is started. Rest when you must but try constantly to bring down your time for each circuit. Try it on for size for 2-3 workouts then start going for time. Keep a regular record of your times and report experiences.

The circuit is designed to develop cardio-circulatory-respiratory efficiency and muscle endurance, involving the major muscle groups as well as the specific areas in which you are most concerned.

The special strength work should be done after a proper cool off and recovery from the circuit work.

1. Knee Head Touch & Press (50 lbs. bar)

2. Stiff Arm Overhead Curl, Press & Squat (50 lbs. bar)

3. Bent Over Row & Leg Exchange (50 lbs. bar)

4. Curl, Press Out, Press Up (50 lbs. bar)
1 rep. is the 3 movements back to starting point.

5. Squat, Straight Arm Pull-Up (50 lbs. bar)

6. Squat, Thrust & Stand (Burpees - 30 lbs. bells)

7. Snatch Split (alternate legs - 50 lbs. - hips low)

8. Double Jacknife Sit-Ups (30 lb. bells)

9. Half Squat Half Curl (50 lbs. bar)

10. Upright Rowing Jump Squats (50 lbs. bar)

COOL OFF:

Jog 15 secs., walk 15 secs. until normal.

All Over Stretch
10 times - real good stretch.

Stomach Pumping (seated)
15 reps.

Jiggle Bounce (REAL LOOSE)
4x15 reps.

Bent Over Stretch (good weight)
10 times.

SPECIAL STRENGTH WORK

1. Dead Life (Back straight)
Best weight for 4x10 reps.

2. Wrist Curl
Natural and Reverse (best weight for each)

3. Bent Over Rowing
3x10 reps. of 85 lbs.

4. Bent Arm Dumb-bell Shoulder Blade Squeeze
Best weight for 3x10 reps.

5, Eccentric Leg Extensions
3x4 reps. on the eccentric ergometer.