ABSTRACT

MARTIN, Charles M. Systolic blood pressure response at selected submaximal heart rates during arm versus leg exercise. M.S. in Adult Fitness and Cardiac Rehabilitation, 1983. 52 pp. (Dr. Glen Porter).

Data were collected on 16 Ss in order to compare systolic blood pressure (SBP) and rate pressure product (RPP) during 4 types of aerobic exercise at 3 submaximal heart rates (HRs). Exercise modalities were arm cranking (AC), rowing (R), treadmill walking (TW), and bicycling (B); and selected HRs were 100, 125 and 150 beats/min. Each S participated in 3 exercise sessions, each to a different target HR and consisting of 4 exercise bouts (1 on each exercise modality) alternating with rest periods. A two-way ANOVA with repeated measures, consisting of 3 levels for HR and 4 levels for exercise type, was used to analyze all data. A Sheffé post hoc analysis was used when necessary to compare paired means. SBP and RPP were significantly greater (p<0.01) during B than AC, R or TW. SBP and RPP were not significantly different (p>0.01) between AC, R or TW. RPP increased significantly (p<0.01) with each increase in HR. SBP was significantly different (p>0.01) between HRs of 100 and 150 beats/min., but not between 100 and 125 beats/min. or 125 and 150 beats/min. Results indicated that although SBP and RPP were statistically greater during B than during AC, R or TW, the differences were too small to be clinically significant. These findings do not demonstrate that SBP and RPP are unusually high at given HRs during arm exercise.
SYSTOLIC BLOOD PRESSURE RESPONSE AT SELECTED SUBMAXIMAL HEART RATES DURING ARM VERSUS LEG EXERCISE

A Thesis Presented to The Graduate Faculty University of Wisconsin-La Crosse

In Partial Fulfillment of the Requirements for the Master of Science Degree

by Charles M. Martin December, 1983
Candidate: Charles M. Martin

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Adult Fitness and Cardiac Rehabilitation.

The candidate has completed his oral report.

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Dedication

This thesis is dedicated to my parents, Mrs. Kathleen Martin and Mr. John Martin. It has been their constant love and support that has instilled in me the confidence and determination necessary to achieve my personal and educational goals. Without their consistent guidance and unwavering love during my formative years, I would never have reached a position to undertake this project.
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CHAPTER I
INTRODUCTION

Upper extremity exercise has gained acceptance, over the past several years, as having a useful and important role in the cardiac rehabilitation process. It is especially beneficial for those patients who intend to resume occupations which predominantly involve arm work and for those who are incapable of leg work, such as paraplegics and those with severe peripheral vascular disease, arthritis or orthopedic problems involving the lower limbs.

A good deal of evidence has been gathered documenting the effectiveness of upper extremity exercise training. Studies by Clausen, Trap-Jensen and Lassen (1970); Magel, McArdle, Toner, and Delio (1978); and Pollock, Miller, Linnerud, Laughridge, Coleman, and Alexander (1974) have illustrated the beneficial training effects of arm exercise in noncardiac subjects. Research has also suggested that upper extremity exercise is effective and safe in the rehabilitation of coronary heart patients (Debusk, Valdez, Houston, & Haskell, 1978; Fardy, Webb & Hellerstein, 1977; Wahren & Bygdman, 1971).

When incorporating arm exercise into the cardiac rehabilitation process, an awareness of the differences between the hemodynamic responses to arm and leg exercise may be important. Increases in heart rate (HR) and systolic blood pressure (SBP) per unit of increase in external work have been shown to be larger for arm exercise than leg exercise (Amundsen, Takahaski, Carter, and Nielson, 1980; Astrand,
Ekblom, Messin, Saltin, & Stenberg, 1965; Bevegard, Freyschuss, & Strandell, 1966; Stenberg, Astrand, Ekblom, Royce, & Saltin, 1967; Wahren & Bydgman, 1971). However, when heart rate and systolic blood pressure comparisons have been made at identical levels of energy cost, several researchers have found the differences to be less pronounced (Amundsen et al., 1980; Astrand et al., 1965; Fardy et al., 1977; Vokak, Bell, Bautz-Holter, & Rodahl, 1975). These hemodynamic findings may be clinically significant when using arm and leg exercise training with coronary heart patients.

Exercise intensity levels for cardiac rehabilitation participants are routinely established after graded exercise testing using the lower extremities. This training intensity or exercise prescription is usually a percentage of the maximal oxygen uptake ($\dot{VO}_2_{\text{max}}$). Since HR and $\dot{VO}_2$ are linearly related during light and moderate exercise, the training intensity is commonly expressed as a heart rate prescription (ACSM, 1980; Amundsen, 1979).

The combination of HR and SBP, when expressed as rate pressure product (RPP), has been documented to be the best indicator of myocardial oxygen cost ($MVO_2$) (Kitamura, Jorgensen, Gobel, & Wang, 1972; Robinson, 1967). Robinson (1967); Schwade, Blomqvist, and Shapiro (1977); and Wahren and Bygdman (1971) have also shown that the onset of myocardial ischemia and resultant angina pectoris are directly related to $MVO_2$ as expressed by RPP. Therefore, it is desirable when exercising coronary heart patients, that the RPP be similar for arm and leg exercise at prescribed training heart rates.
Purpose

The purpose of this study was to examine the significance of differences in SBP and RPP at three submaximal heart rates during arm and leg exercise. Four commonly employed cardiovascular training modalities were utilized; they were the treadmill, bicycle ergometer, stationary rowing machine, and arm crank ergometer. The selected submaximal heart rates were 100, 125 and 150 beats per minute.

Need for the Study

Past studies of hemodynamic responses to arm versus leg exercise have compared HR, SBP and RPP in relation to external work load or to \( \dot{V}O_2 \). The findings of these investigations have consistently shown that HR and SBP rise more steeply in relation to external work load during arm exercise, but that the difference is much less pronounced when related to \( \dot{V}O_2 \).

No investigations were found, however, which had been done to compare SBP and RPP in relation to HR during arm versus leg exercise. When exercising coronary heart patients, heart rate, rather than \( \dot{V}O_2 \) or external work load, is routinely used to indicate exercise intensity. For this reason and because of the suggested relationship between RPP and the onset of myocardial ischemia and angina pectoris, an investigation of SBP and RPP in relation to HR is needed.

An investigation comparing a variety of arm and leg training modalities is also needed. Most previous studies have utilized only two types of exercise—usually arm crank ergometry and either treadmill walking/running or stationary bicycle ergometry; few studies have examined circulatory responses to stationary rowing. Many cardiac
rehabilitation programs, however, employ an assortment of arm and leg modalities, including rowing, in an alternating circuit fashion.

Null Hypothesis

It was hypothesized that there would be no significant difference (p > .05) in systolic blood pressure or in rate pressure product, when compared at any of the submaximal heart rates of 100, 125 or 150 beats per minute, during arm cranking, stationary rowing, treadmill walking, and stationary bicycling.

Assumptions

The following basic assumptions were made for the purpose of this investigation:

1. All subjects were healthy, without any significant hemodynamic abnormalities.
2. The physiological monitoring devices were functioning properly and correctly calibrated.
3. The unfamiliar laboratory environment had minimal effect on the performance of the subjects or on their hemodynamic characteristics.

Delimitations

The delimitations of this investigation were:

1. All subjects were male volunteers, 21 to 30 years of age, who lived in the La Crosse, Wisconsin, area.
2. Only three submaximal heart rates were used. They were pre-selected to be 100, 125 and 150 beats per minute.
3. All blood pressure data were recorded by one investigator, using the same sphygmomanometer and stethoscope throughout the study.
Limitations

The following were limitations of this investigation:

1. Random sampling was not used for subject selection.

2. The amount and type of aerobic conditioning in which the subjects might have been involved was not controlled during this study.

3. Blood pressure and heart rate determinations were not performed simultaneously during this investigation. Heart rate was recorded just prior to the completion of each exercise bout. Blood pressure was measured approximately 10 seconds later, just after the completion of the exercise.

Definition of Terms

Heart Rate (HR) - The number of times the heart contracts per minute. Heart rate was determined in this study by counting the number of QRS complexes in a six-second segment of an electrocardiographic rhythm strip and multiplying that number by ten.

Myocardial Oxygen Consumption ($\dot{V}O_2$) - The amount of oxygen utilized by the heart in performing its pumping function. $\dot{V}O_2$ is usually estimated from the product of the heart rate and systolic blood pressure which is known as the rate pressure product.

Oxygen Consumption ($\dot{V}O_2$) - The amount of oxygen utilized by the body in performing a given level of external work. $\dot{V}O_2$ is usually expressed in L·min$^{-1}$ or ml·kg$^{-1}$·min$^{-1}$.

Rate Pressure Product (RPP) - An indirect index of myocardial oxygen consumption. RPP was calculated in this investigation by multiplying heart rate times systolic blood pressure times 10$^{-2}$. 
Systolic Blood Pressure (SBP) - The pressure exerted by the blood on the wall of any blood vessel during the contraction phase of the heart cycle. SBP, in this study, referred to the indirect measurement of pressure in the right brachial artery with a standard cuff and sphygmomanometer.
CHAPTER II
REVIEW OF RELATED LITERATURE

Several associated areas of research were disclosed during a review of related literature. The three topics of investigation recognized as being most relevant to this study were: 1) comparisons of hemodynamic responses to submaximal arm versus leg exercise, 2) comparisons of hemodynamic responses to various types of leg exercise or arm exercise and 3) investigations of the relationship between RPP and the onset myocardial ischemia and angina pectoris during arm versus leg exercise. This chapter is divided into three sections corresponding to these areas of pertinent research.

Hemodynamic Responses to Submaximal Arm Versus Leg Exercise

Numerous studies have been done comparing physiological responses during lower extremity work to those during exercise using the upper extremities. Only a limited number, however, have compared hemodynamic responses during submaximal work. Findings of these studies, although indicating that circulatory responses do differ between arm work and leg work, are conflicting and sometimes confusing. An attempt is made in this section, to organize the findings of the studies and to provide possible explanations for the conflicting results.
Heart Rate Response

Research has consistently demonstrated that the HR response is markedly more pronounced in relation to work load during arm exercise than during leg work (Amundsen et al., 1980; Bevegard et al., 1966; Bobbert, 1960; Stenberg et al., 1967; Vokac et al., 1975; Wahren & Bydgosn, 1971). Findings have been less consistent, however, when HR responses are compared in relation to $\dot{V}O_2$ level.

Using six healthy male subjects, Bobbert (1960) compared several physiological responses to submaximal walking, cycling and cranking. He found that HR was always higher in cranking than walking or cycling when performing equal amounts of external work. His findings further indicated, in contrast to most studies, that HR increased at the same rate in relation to $\dot{V}O_2$ regardless of the type of work performed.

A study done by Vokac et al. (1975) yielded somewhat different results. Seven healthy male subjects performed cycling, sitting arm cranking and standing arm cranking, and $\dot{V}O_2$ and HR responses were compared at three external work loads. Both $\dot{V}O_2$ and HR were found to be similar during low level arm work and leg work but markedly higher during arm exercise at more strenuous workloads. Since $\dot{V}O_2$ and HR increased concomitantly during both arm work and leg work, HR values differed far less when compared at equal $\dot{V}O_2$ levels than at equal external work loads. Because HR and $\dot{V}O_2$ responses were closer to being parallel during leg work than during arm work, however, there were significant differences between heart rates at high $\dot{V}O_2$ levels; arm work elicited higher heart rates.
After further analyzing their data, Vokac et al. (1975) provided a possible explanation for the disparity between their findings and those of the study done by Bobbert in 1960. They found that the rate of HR adjustment to increased energy demands is not the same during arm exercise and leg exercise. During leg work, even at high $\dot{V}O_2$ levels, HR was found to reach an appropriate level in the first two minutes and plateau at that level. During arm exercise at high $\dot{V}O_2$ levels, on the other hand, HR was found to continue rising for more than six minutes without beginning to plateau. Because the workloads used in Bobbert's (1960) experiment were relatively light, this difference in the rate of HR adjustment to arm versus leg work did not come into play.

Several additional studies have been done which corroborate the findings of Vokac et al. (1975). Anundsen et al. (1980), Astrand et al. (1965), Bevegard et al. (1966), and Stenberg et al. (1967) all found that HR is higher in relation to $\dot{V}O_2$ during arm exercise than during leg work. Two of the studies, those by Bevegard et al. (1966) and Stenberg et al. (1977), are particularly helpful in explaining the increased HR response during arm work.

Bevegard et al. (1966) used cardiac catheterization to investigate hemodynamic adaptation to arm, leg and combined arm and leg exercise in supine and sitting positions. During arm work, heart rate was found to increase more in relation to $\dot{V}O_2$ in both erect and supine positions. Additional hemodynamic findings helped explain the variation in HR response. At equal $\dot{V}O_2$ levels in the upright position, cardiac outputs were not significantly different during arm, leg or combined arm and leg exercise, although stroke volume was significantly smaller during
arm work. The researchers concluded from these findings that the more pronounced HR response during arm exercise was due, at least in part, to the reduced stroke volume. The researchers were unable, however, to explain why the HR response remained more pronounced during arm work in the supine position even though the stroke volume was not significantly different during arm, leg or combined exercise.

Stenberg et al. (1967) performed an experiment very similar to that of Bevegård et al. (1966) and further elucidated the increased HR response during arm exercise. Again, cardiac catheterization was used to investigate circulatory responses to arm, leg and combined exercise in supine and sitting positions. The findings were very similar, with one important exception, to those of Bevegård et al. (1966). In the supine position, not only HR but also cardiac output was found to be higher during arm work than during leg work. (Bevegård et al. showed a similar trend but, possibly because smaller work loads were used, the difference in cardiac output was not significant.) Because of the higher cardiac output during supine arm exercise, differences in stroke volume were not as pronounced. This piece of evidence allowed the researchers to confirm the evidence of earlier studies which indicated that the increased HR response during upright arm exercise is a compensatory adjustment to maintain cardiac output. It was further concluded that the diminished stroke volume during arm work in the upright position was caused by decreased venous return resulting from increased venous pooling in the lower extremities.
Systolic Blood Pressure Response

Systolic blood pressure, like HR, has in most studies been shown to be more pronounced during arm work than during leg work. More pronounced SBP responses have been demonstrated during arm work at comparable $\dot{V}O_2$ levels as well as at equal external work loads (Åstrand et al., 1965; Bevegård et al., 1966; & Stenberg et al., 1967).

Findings of a recent study by Amundsen et al. (1980), however, were contrary to the findings of the earlier investigations. Systolic blood pressure response was not found to be significantly different during arm versus leg exercise. The researchers attributed their contradictory findings to the fact that all SBP responses were monitored at the brachial artery during their investigation. They used the results of a study done by Åstrand et al. in 1965 to explain the apparent lack of difference.

Åstrand et al. used percutaneous catheterization of the femoral artery to compare intra-arterial pressure in 13 subjects during arm and leg exercise. In order to ascertain the influence of catheter location on blood pressure readings, brachial as well as femoral catheters were used in three subjects and simultaneous blood pressure measurements were obtained. Several interesting findings resulted. Femoral blood pressure readings indicated that blood pressure increased linearly with $\dot{V}O_2$, and that the increase was significantly more pronounced with arm work than with leg work. Simultaneous brachial and femoral pressures demonstrated that the difference in SBP response between arm and leg work was substantially reduced when blood pressure was monitored in the brachial artery. It was further shown that SBP
readings for the working extremity were always lower when measured in that extremity, and that SBP readings in the resting extremity were always higher than simultaneous measurements in the working limb.

These findings explain the apparent conflict in the results of the study done by Amundsen et al. in 1980. When blood pressures are obtained from the brachial artery (as they were in the study by Amundsen et al.), SBP readings during arm work are diminished and readings during leg work are magnified. Thus, if aortic SBP is in fact higher during arm work than during leg work, the difference is neutralized when pressure readings are obtained at the brachial artery.

When blood pressures were monitored by means of a catheter in the aortic arch, in a study by Bevegård et al. (1966), SBP response was found to be significantly more pronounced during arm work than during leg work at comparable VO₂ levels. Interestingly, aortic SBP was also found to increase more in relation to cardiac output during arm exercise. This indicated that total peripheral vascular resistance was higher with arm exercise than with leg work. These findings are in agreement with those of the study done by Astrand et al. in 1965.

Both Bevegård et al. (1966) and Astrand et al. (1965) offered the same explanation for the increased total peripheral vascular resistance during arm work. It has been shown that during exercise resistance vessels dilate in the active muscles and constrict in the inactive muscles due to an increase in sympathetic activity (Bevegård & Shepherd, 1965). The same researchers showed that the increase in vasoconstrictor activity in the inactive extremities is proportionate to the intensity of work. It is not likely that the increased
sympathetic vasoconstrictor activity is confined to the inactive muscles. It was, therefore, assumed that the vasoconstrictor activity is overcome in the exercising muscles by a more powerful local vasodilator mechanism. Thus, it is likely that higher total peripheral vascular resistance will result when work is done with a small muscle group (such as the arms) when a relatively small portion of the vascular bed is dilated in comparison to the large portion, in the inactive muscles, which remains constricted. Since cardiac output is the same during arm work and leg work, the higher SBP readings which occur during arm work are due to the increased total peripheral vascular resistance.

Hemodynamic Responses to Different Types of Submaximal Exercise Using the Same Extremity

Although many investigators have compared physiological responses to different types of leg exercise, very few have focused on submaximal hemodynamic responses. Instead, most have examined metabolic, ventilatory and oxygen consumption variables. Even fewer investigations have been done comparing circulatory responses to various types of arm exercise. The few studies which have compared hemodynamic responses to different types of exercise using the same extremity are reviewed in this section.

Lower Extremity Exercises

The most comprehensive comparison of hemodynamic responses to different types of submaximal leg exercise was done by Hermanson, Ekblom and Saltin (1970) using stationary bicycling and uphill treadmill running. Thirteen healthy males were the subjects. Heart rate, \( \dot{V}O_2 \),
cardiac output, arterial blood pressure, and $a-vO_2$ difference were measured; cardiac output and arterial blood pressure measurements were obtained via catheterization of the brachial artery. At comparable submaximal $\dot{V}O_2$ levels, heart rate and blood pressure were found to be significantly higher, stroke volume (SV) was smaller, and cardiac output was similar during bicycling versus running.

Again, as with comparisons of arm and leg exercise, these findings seemed to indicate that the more pronounced HR response during biking was a compensatory mechanism to maintain cardiac output in light of diminished stroke volume. The researchers attributed the diminished stroke volume to higher intramuscular pressures during biking which restricted blood flow through that area. Their findings of increased acidosis and pulmonary ventilation during submaximal biking seemed to confirm this explanation. Restricted blood flow during biking probably leads to decreased venous return and, in turn, smaller stroke volume.

The same mechanism may have been responsible for the more marked blood pressure response during submaximal cycling. Restricted blood flow in the legs probably caused an increased total peripheral vascular resistance which, in conjunction with cardiac outputs equal to those recorded during running, resulted in higher blood pressures. It is also possible that the decreased peripheral vascular resistance during uphill running was due to dilation of a larger portion of the vascular bed resulting from increased use of the arms during running.

Miles, Kritz and Knowlton (1980) compared submaximal cardiovascular responses during treadmill walking and bicycle ergometry using 18 females as subjects. Contrary to the findings of Hermanson et al. (1970),
no difference was found in HR or SV during cycling versus treadmill walking at identical submaximal $\dot{V}O_2$ levels. The investigators offered several possible explanations for their contradictory findings. It is most likely that the low workloads used on the bicycle ergometer (150-650 kpm) were not sufficient to restrict blood flow and thereby decrease venous return. Secondly, the hemodynamic responses during treadmill walking may vary significantly from those during treadmill running. Finally, it is possible that there is a sex difference in the cardiovascular responses to various types of submaximal leg work.

Another study, done by Faulkner, Roberts, Elk, and Conway (1971), yielded results which were in agreement with those of the study done by Hermanson et al. (1970). Cardiovascular responses of eight healthy males were compared during cycle ergometry and treadmill running. HR was found to be higher during cycling than during running at equal submaximal $\dot{V}O_2$ levels. SV was smaller and HR was higher during submaximal cycling, but cardiac output was the same during cycling and running at equal $\dot{V}O_2$ levels. When data were collected at five and ten minutes during work at $\dot{V}O_2$ level of 90-95% of maximum, another interesting finding resulted. During cycling, HR increased significantly between the fifth and tenth minutes. HR did not change significantly over the same time period during treadmill running.

This finding offered an additional possible explanation for the apparently contradictory results of the investigation done by Miles et al. (1980). Submaximal exercise stages during their study were only six minutes in length, while the studies by Hermanson et al. (1970) and Faulkner et al. (1971) the exercise stages were eight and ten
minutes long, respectively. It was likely that the six-minute stages were not sufficient to allow the HR to increase to its plateau level during cycling.

**Upper Extremity Exercises**

Only one previous investigation was found which compared submaximal hemodynamic responses to arm cranking and stationary rowing (the upper extremity exercises used in the present investigation). Meyer (1980) measured HR, SBP and RPP responses using 20 healthy college age males as subjects. Values for each variable were compared for the two types of arm work at 50%, 60%, 70%, 80% and 90% of maximal \( \dot{V}O_2 \) and at maximum work capacity. No significant differences were found between the two types of exercise for any of the variables at any of the work levels.

In a study by Amundsen, et al. (1980), submaximal cardiovascular responses were compared during wall pulley pulling and wall pulley pushing. Fifteen normal males with a mean age of 30.2 years were used as subjects. Both types of exercise were performed at intensity levels of 65, 104, 140, 197 and 214 kpm·min\(^{-1}\). All exercise stages were five minutes in length. Regression equations were calculated for HR, SBP and RPP versus \( \dot{V}O_2 \) for each type of exercise. None of the variables were found to differ significantly between the two types of exercise when compared at equal \( \dot{V}O_2 \) levels.

Cardiorespiratory responses to submaximal and maximal arm cranking and wheel chair cranking were compared in a study done by Sawka, Glasser, Wilde, and Lahrte (1980). Six wheel chair dependent and ten able-bodied males were used as subjects. Progressive intensity discontinuous
protocols, consisting of seven-minute exercise stages alternating with five-minute rest periods, were used for both types of exercise. Exercise intensities consisted of 30, 90, 150, and 210 kpm·min⁻¹. When VO₂, cardiac output, SV, HR, SBP, and RPP were compared for the two types of exercise, all values were higher at each submaximal exercise intensity during wheelchair ergometry than during arm cranking. Regression equations were also computed for cardiac output and RPP versus VO₂. Cardiac output and RPP were both found to be higher in relation to VO₂ during wheelchair work. The authors attributed the increased RPP response during wheelchair work to increased total peripheral vascular resistance. Because wheelchair exercise utilized a smaller skeletal muscle mass, a proportionally larger area of the vascular bed, supplying the inactive skeletal muscle, remained constricted. As a result, the total peripheral vascular resistance was elevated.

Rate Pressure Product and the Onset of Myocardial Ischemia During Arm Versus Leg Exercise

Rate Pressure Product (RPP) has been demonstrated to be the most accurate easily-measurable predictor of myocardial oxygen consumption (ṀVO₂) (Kitamura et al., 1972). HR, SBP, VO₂, coronary blood flow, and systolic ejection period were measured in ten healthy male subjects with a mean age of 22.9 years. Data were collected at three levels of upright bicycle exercise. Correlation coefficients were then calculated for HR, SBP, RPP, VO₂, work load, and Tension Time Index (SBP x systolic ejection period) versus coronary blood flow and ṀVO₂. Correlations
were low between SBP, Tension Time Index, work load, and $\dot{V}O_2$ versus $\dot{M}VO_2$; $r = .75, .77, .79$ and $.80$, respectively. The correlation between HR and $\dot{M}VO_2$ was much higher ($r = .88$). The highest coefficient, however, was found for the correlation between RPP and $\dot{M}VO_2$ ($r = .90$).

Much research has been done which demonstrates that symptoms of myocardial ischemia in cardiac patients are evoked during exercise at consistent individual $\dot{M}VO_2$ thresholds regardless of the type of exercise. Because of its high correlation with $\dot{M}VO_2$ and because it is easily measureable, RPP has been used as the indicator of $\dot{M}VO_2$ in all of these studies.

Robinson (1967) studied the circulatory responses of 15 patients with angina pectoris while pain was evoked during various types of exercise. Arterial pressure was measured by way of a catheter located in the subclavian artery. The various types of exercise used were stationary bicycling, stair stepping, running, and repetitive lifting of a two-pound weight. Results of the investigation indicated that the onset of angina was related to a critical level of RPP which remained essentially constant in each subject. The relationship did not vary significantly even with large variations in type, intensity or duration of exercise.

In a similar study, Wahren and Bygdman (1971) measured circulatory responses during arm cranking and stationary cycling in ten patients with histories of angina pectoris. SBP and HR were both found to rise more steeply in relation to work load and $\dot{V}O_2$ during arm exercise than during leg exercise. Angina was thus evoked at lower workloads and $\dot{V}O_2$ levels during arm work. Consistent with the findings of Robinson
(1967), however, anginal pain occurred at the same RPP level during both arm and leg exercise.

Schwade, Blomqvist and Shapiro (1977) also compared circulatory responses to arm cranking and bicycle ergometry. Their subjects were 33 patients with documented ischemic heart disease; 19 had histories of prior myocardial infarction and 14 had an angiographically demonstrated obstruction of 75% or more in at least one coronary artery. Subjects performed both an arm and a leg graded exercise test. Both test protocols consisted of three-minute, 150 kpm·min\(^{-1}\) stages. Test endpoints were anginal pain, 1.0 mm of ST depression or elevation, ventricular irritability, fatigue, or achievement of 90% of age-predicted maximal heart rate. In contrast to the studies by Robinson (1967) and Wahren and Bygdman (1971), arterial blood pressure was measured indirectly. Results of the investigation were in agreement with those of the previous studies. Arm work and leg work produced ischemic responses with equal frequency although arm work evoked them at 40% of the workload achieved during leg work. The RPP threshold at which ischemic responses, either angina or ST abnormalities, appeared was similar for both types of exercise.

Only one investigation was found in the literature which was not in agreement with the above-mentioned studies. Clausen and Trap-Jensen (1976) measured circulatory responses during arm cranking and stationary cycling in 29 patients with typical angina pectoris. Intra-arterial and noninvasive indirect blood pressure readings were obtained during both types of exercise. In contrast to other studies, the RPP threshold at which angina was evoked was found to be consistently higher during
arm exercise than during leg exercise. The authors were unable to explain their apparently contradictory findings. Another interesting (and pertinent to the present study) finding was that the SBP values obtained by a noninvasive cuff technique did not differ significantly from those obtained via an intra-arterial catheter.

The study which was found to relate most directly to the present study was one carried out by I. Astrand in 1972. HR, SBP and ST depression were studied during arm versus leg exercise in 17 patients with previous histories of exercise induced ST depression. As in other investigations, HR and SBP were greater during arm work than during leg work. The new and unique finding of the study, however, was that EKG demonstrated ST depression was greater during arm work than during leg work at a given $\dot{V}O_2$ level or at a given HR. This could indicate that SBP and thus $M\dot{V}O_2$ as predicted by RPP are greater at a given $\dot{V}O_2$ or HR during arm exercise.

**Summary**

Many investigations have shown that HR and SBP increases are greater in relation to $\dot{V}O_2$ during exercise using relatively small muscle groups than during exercise with larger muscle groups. This finding has been found to hold true when different types of exercise using the same extremity have been compared as well as with comparisons of upper and lower extremity exercise. Research has also demonstrated conclusively that myocardial ischemia is evoked in cardiac patients during exercise at a threshold RPP level which remains relatively constant in a given individual regardless of the type, intensity or duration of exercise. In addition, one study was found in the literature which indicated that
ST depression is greater at a given HR during arm exercise than during leg exercise. That indication, however, was an unexpected and indirect finding of the study. It is possible that the greater ST depression during arm work at equivalent heart rates was due to higher MVO$_2$ as indicated by RPP. No investigation comparing SBP response at selected target heart rates during arm and leg exercise was found in the literature.
CHAPTER III

METHODS AND PROCEDURES

Subject Selection

Sixteen healthy male volunteers between 20 and 30 years of age took part in the study. All of the subjects were physically active but none took part in competitive athletics at the time of the study. Each subject read and signed an informed consent form before participating in the study (see Appendix A). Means and standard deviations for the age, height and weight of the subjects are as follows: age, 25.9 ± 2.89 years; height, 181.0 ± 4.95 cm (71.3 ± 1.95 inches); and weight, 77.0 ± 7.02 kg (169.4 ± 15.46 pounds).

Procedures

All subjects took part in three submaximal exercise sessions on separate days within a three-week period. Each testing session consisted of exercise on four aerobic exercise modalities to one of three pre-selected submaximal target heart rates. The exercise sessions were designed to be similar to the circuit-type of training sessions which are often used in phase II cardiac rehabilitation. Arm cranking, stationary rowing, treadmill walking, and stationary bicycling were the exercise modalities used and the pre-selected target heart rates were 100, 125 and 150 beats per minute. The order in which the four types of exercise were performed was determined randomly at each exercise session. Possible exercise orderings were limited so that arm and
leg exercise was always performed in alternating order. At the time of the initial exercise session, the order of the target heart rates for the three sessions was also determined randomly. All testing was performed in the Cardiac Rehabilitation Exercise Laboratory of the Gundersen Clinic in La Crosse, Wisconsin.

Each subject was familiarized with the laboratory setting and with the purpose and procedure of the study at the time of his initial visit to the laboratory. At that time, the subject was also given the informed consent form to read and sign. Weight and height were then recorded in pounds and inches, respectively. The values were later converted to appropriate metric measurements.

**Test Administration and Data Collection**

After entering the laboratory and completing the initial procedures mentioned above, the subject was prepared for data collection. Heart rate and blood pressure were the variables measured.

Heart rates were continually monitored during all exercise sessions by means of a Hewlett-Packard Telemetry Unit, using a bipolar lead system. Minute heart rates were determined by counting the number of QRS complexes in a six-second strip and multiplying that number by ten. Electrocardiographic tracings for the purpose of determining heart rate, were recorded during the last ten to twenty seconds of each exercise stage.

Three electrodes were placed in order to monitor the bipolar lead. Electrode placement sites were the manubrium of the sternum and at the right and left mid-clavicular lines on the inferior ribs. These sites were chosen in order to minimize the amount of artifact caused by
muscle contraction during upper extremity exercise. Preparation of the placement sites consisted of shaving the appropriate areas if necessary, abrasion of the skin in those areas with an alcohol pad and further abrasion using a dry gauze pad.

Indirect arterial blood pressure measurements were obtained by means of auscultation using a standard cuff and sphygmomanometer. For the sake of consistency, all readings were taken after the completion of each exercise stage. Because accurate SBP readings could not be obtained during arm exercise due to arm movement, SBP measurements for both arm and leg exercise were taken immediately after the completion of exercise. All readings were obtained within 20 seconds after the termination of exercise. The blood pressure cuff was placed on the right arm approximately one to two inches above the elbow. In order to prevent the cuff from becoming overly tight and restricting blood flow during arm exercise, it was wrapped snugly but not tightly around the arm. With some subjects, it was necessary to tape the cuff in place to prevent it from sliding down the arm. The brachial artery was then palpated and marked with a felt tip pen in order to facilitate rapid and consistent blood pressure measurements.

After the subject had been prepped, he remained seated while lead wires from the telemetry unit were connected to the three electrodes and a resting heart rate was obtained. A resting blood pressure was also taken with the subject still in a sitting position. The subject was then positioned at the appropriate exercise modality (as determined by the randomly selected ordering already mentioned) and the test was begun.
An identical testing protocol was used for each of the three exercise sessions except that the target heart rate was different for each session—either 100, 125 or 150 beats per minute. The protocol consisted of four exercise bouts, one at each modality, separated by rest periods. Each exercise bout consisted of a brief warm-up period, a two to three minute stage during which the exercise intensity was increased to produce the appropriate target rate and a three minute steady state during which the heart rate was fine-tuned to within ±5 beats per minute of the target heart rate by making minor adjustments in work load. Rest periods lasted three to five minutes or until the heart rate had returned to near resting level. Heart rate and blood pressure measurements were obtained for each exercise bout as described earlier. Rate pressure products were computed later by multiplying heart rate times systolic blood pressure and dividing that product by 100. Resting and exercise data from all three testing sessions were recorded on a single data sheet (see Appendix B).

**Instrumentation**

Arm cranking, stationary rowing, treadmill walking, and stationary bicycling were the exercise modalities chosen for this study because they are commonly used in phase II cardiac rehabilitation. The Gundersen Clinic phase II program uses all four modalities, alternating arm and leg exercise in a circuit training program.

Arm cranking, during the study, was performed on a Monarh Rehab Trainer which was secured to the top of a table so that the axle of the ergometer was at approximately shoulder height when subjects were seated. The subject was seated at a distance from the ergometer which enabled
the arms to be horizontally stretched alternately while cranking. The handles could be grasped comfortably from this position without forward lean of the torso. Cranking speed and resistance were adjusted subjectively to elicit the selected target heart rate. During arm cranking exercise at a heart rate of 150, three subjects were unable to maintain the necessary workload for three minutes at steady state. Cranking was terminated for these individuals after two minutes of steady state.

An Everlast hydraulic resistance rowing machine was used for stationary rowing. Resistance was adjusted separately for the two oars by means of a T-knob located at the pivot point of each oar. A crude calibration system was devised by evenly spacing numbered reference marks around the base of each T-knob. The reference marks simplified adjustments of resistance and made it possible to maintain equal resistance for both oars. Although the rowing machine included a sliding seat to incorporate leg work into the rowing motion, it was not used during the study. In order to eliminate leg involvement and thereby isolate the upper body, subjects were instructed to keep their knees extended throughout rowing exercise. Verbal instructions to keep the legs fully extended were given frequently during the exercise bout. Rowing cadence was guided by means of an electric metronome. Cadence and resistance of the rowing were adjusted subjectively to produce the appropriate target heart rate. Most subjects found it easier to maintain rowing at high workloads if the resistance was kept relatively low and the cadence relatively fast.

Stationary cycling was performed on a Monarch bicycle ergometer
and treadmill walking was done on an IMC (Model 200) portable motor driven treadmill. Seat height was set on the bike ergometer so that the knee of the extended leg was just short of full extension with the ball of the foot on the pedal and the pedal at the bottom of its revolution. Treadmill speed and grade were manipulated so that subjects attained only walking speeds. As with the arm modalities, workloads were adjusted subjectively to elicit the selected target heart rate.

**Statistical Analysis of Data**

A two-way analysis of variance with repeated measures, with three target heart rate groupings and four groupings for exercise modality, was used to test the null hypothesis for each variable. Where significant F ratios were found, the Sheffé post hoc test was used to determine the significance between all paired means. The .01 level of significance was used to reject each null hypothesis. The Biomedical Computer Program (University of California, 1981) was used for the statistical analysis. Computer data were compiled and analyzed at the University of Wisconsin-La Crosse computer center.
CHAPTER IV
RESULTS

Means, standard deviations and ranges for HR, SBP and RPP during arm cranking, rowing, bicycling and treadmill walking at target heart rates of 100, 125 and 150 are given in Tables 1, 2 and 3, respectively.

Because this experiment was designed to elicit consistent HR values for the four types of exercise at each target heart rate, there were only minor differences in HR between exercise types. The range of mean HR values for the four types of exercise was no more than two beats per minute at any of the three target heart rates. The ranges were: 100.3 - 102.3 beats/min at a target heart rate of 100, 125.5 - 127.5 beats/min at a target heart rate of 125 and 150.4 - 152.3 at a target heart rate of 150. Figure 1 indicates the consistency of HR values between the various exercise types.

Brachial SBP was found to increase slightly but not significantly (p > 0.01) with each increase in target HR. It is also evident in Tables 1, 2 and 3 that SBP was higher during bicycling at every target heart rate than during any of the other types of exercise. A summary of the two-way analysis of variance for SBP is shown in Table 4. Results of the analysis of variance indicated that significant differences (p < 0.01) in SBP existed between various exercise types as well as between different target heart rates. Application of the Sheffé post hoc test to determine differences between paired SBP means for
Table 1. Hemodynamic Values for Four Types of Exercise at
a Target Heart Rate of 100 Beats Per Minute

<table>
<thead>
<tr>
<th></th>
<th>Arm Crank</th>
<th>Rower</th>
<th>Bicycle</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate (Beats/Min)</td>
<td>X</td>
<td>101.6</td>
<td>100.3</td>
<td>102.3</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.6</td>
<td>3.0</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>97-105</td>
<td>97-104</td>
<td>96-106</td>
</tr>
<tr>
<td>Systolic Blood Pressure (mmHg)</td>
<td>X</td>
<td>122.3</td>
<td>123.5</td>
<td>127.1</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>9.5</td>
<td>13.6</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>110-132</td>
<td>106-150</td>
<td>100-142</td>
</tr>
<tr>
<td>Rate Pressure Product</td>
<td>X</td>
<td>124.2</td>
<td>123.3</td>
<td>130.2</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>10.3</td>
<td>14.2</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>110.0-153.3</td>
<td>96.0-156.0</td>
<td>101.0-142.8</td>
</tr>
</tbody>
</table>

Rate Pressure Product = Heart Rate X Systolic Blood Pressure/100
<table>
<thead>
<tr>
<th></th>
<th>Arm Crank</th>
<th>Rower</th>
<th>Bicycle</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heart Rate (Beats/min)</strong></td>
<td>$\bar{X}$</td>
<td>126.4</td>
<td>125.5</td>
<td>127.5</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>2.1</td>
<td>2.6</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>122-130</td>
<td>121-130</td>
<td>124-130</td>
</tr>
<tr>
<td><strong>Systolic Blood Pressure (mmHg)</strong></td>
<td>$\bar{X}$</td>
<td>134.6</td>
<td>132.6</td>
<td>142.6</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>12.8</td>
<td>13.6</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>120-172</td>
<td>106-154</td>
<td>122-178</td>
</tr>
<tr>
<td><strong>Rate Pressure</strong></td>
<td>$\bar{X}$</td>
<td>170.2</td>
<td>166.3</td>
<td>182.0</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>15.4</td>
<td>17.8</td>
<td>20.2</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>152.4-216.7</td>
<td>133.6-197.1</td>
<td>160.0-224.3</td>
</tr>
</tbody>
</table>

Rate Pressure Product = Heart Rate $\times$ Systolic Blood Pressure/100
Table 3. Hemodynamic Values for Four Types of Exercise at a Target Heart Rate of 150 Beats Per Minute

<table>
<thead>
<tr>
<th></th>
<th>Arm Crank</th>
<th>Rower</th>
<th>Bicycle</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heart Rate</strong></td>
<td>$\bar{x}$</td>
<td>150.9</td>
<td>150.4</td>
<td>152.3</td>
</tr>
<tr>
<td>(Beats/min)</td>
<td>SD</td>
<td>3.0</td>
<td>2.6</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td></td>
<td>147-157</td>
<td>145-154</td>
<td>149-155</td>
</tr>
<tr>
<td><strong>Systolic Blood</strong></td>
<td>$\bar{x}$</td>
<td>137.6</td>
<td>142.4</td>
<td>149.9</td>
</tr>
<tr>
<td>Pressure (mmHg)</td>
<td>SD</td>
<td>11.6</td>
<td>15.3</td>
<td>17.2</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td></td>
<td>114-154</td>
<td>104-168</td>
<td>118-176</td>
</tr>
<tr>
<td><strong>Rate Pressure</strong></td>
<td>$\bar{x}$</td>
<td>207.5</td>
<td>214.2</td>
<td>228.0</td>
</tr>
<tr>
<td>Product</td>
<td>SD</td>
<td>17.2</td>
<td>22.7</td>
<td>25.1</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td></td>
<td>173.3-232.5</td>
<td>158.1-257.0</td>
<td>182.9-271.0</td>
</tr>
</tbody>
</table>

Rate Pressure Product = Heart Rate $\times$ Systolic Blood Pressure/100
Figure 1. Heart Rates During Four Types of Exercise at Three Target Heart Rates

Arm Crank
Rowing Machine
Bicycle
Treadmill
target heart rates demonstrated that there was a significant difference (p < 0.01) in SBP between target heart rates of 100 and 150, but that the increases between the target heart rates of 100 and 125 and between 125 and 150 were not significant (p > 0.01). When the Sheffé test was used to analyze differences between paired means for the four exercise types, SBP during bicycling was found to be significantly higher (p < 0.01), in relation to target heart rate, than during any of the other types of exercise. Differences in SBP between arm cranking, rowing and treadmill walking were not significantly different (p > 0.01). The relationship between SBP values for the three target heart rates and four exercise types is presented in Figure 2.

Tables 1, 2 and 3 indicate that, as would be expected, RPP increased markedly with each increase in target heart rate. It is also evident from the tables that RPP, like SBP, was greater during bicycling than during the other three types of exercise. Table 5 presents a summary of the two-way analysis of variance for RPP. Results of the two-way analysis indicated that RPP varied significantly (p < 0.01) between target heart rates and between different exercise types. Sheffé post hoc analysis of differences between paired RPP means for target heart rates indicated that each increase in target heart rate resulted in a significant (p < 0.01) increase in RPP. Post hoc analysis of differences between paired means for exercise types indicated that RPP during bicycling was significantly higher, in relation to target heart rate, than during any of the other three types of exercise. Differences in RPP between arm cranking, rowing and treadmill walking were not significant (p > 0.01). Figure 3 presents the relationship between RPP values for the three target heart rates and four exercise types.
Table 4. Two-Way Analysis of Variance: Systolic Blood Pressure
During Four Types of Exercise at Three Target Heart Rates

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Heart Rate</td>
<td>9569.63</td>
<td>2</td>
<td>4784.81</td>
<td>6.82</td>
<td>.003</td>
</tr>
<tr>
<td>Residual</td>
<td>31568.38</td>
<td>45</td>
<td>701.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise Type</td>
<td>2245.17</td>
<td>3</td>
<td>748.39</td>
<td>10.19</td>
<td>.000</td>
</tr>
<tr>
<td>Interaction</td>
<td>773.71</td>
<td>6</td>
<td>128.95</td>
<td>1.76</td>
<td>.113</td>
</tr>
<tr>
<td>Residual</td>
<td>9915.13</td>
<td>135</td>
<td>73.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjects</td>
<td>3447552.00</td>
<td>1</td>
<td>3447552.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3447552.00</td>
<td>192</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Systolic Blood Pressures During Four Types of Exercise at Three Target Heart Rates
Table 5. Two-Way Analysis of Variance: Rate Pressure Product
During Four Types of Exercise at Three Target Heart Rates

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Heart Rate</td>
<td>249135.54</td>
<td>2</td>
<td>124567.77</td>
<td>106.22</td>
<td>.000</td>
</tr>
<tr>
<td>Residual</td>
<td>52774.63</td>
<td>45</td>
<td>1172.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise Type</td>
<td>5429.63</td>
<td>3</td>
<td>1809.88</td>
<td>12.63</td>
<td>.000</td>
</tr>
<tr>
<td>Interaction</td>
<td>1727.75</td>
<td>6</td>
<td>287.96</td>
<td>2.01</td>
<td>.069</td>
</tr>
<tr>
<td>Residual</td>
<td>19347.13</td>
<td>135</td>
<td>143.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subjects</td>
<td>5608801.33</td>
<td>1</td>
<td>5608801.33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total
Figure 3. Rate Pressure Products During Four Types of Exercise at Three Target Heart Rates

- Arm Crank
- Rowing Machine
- Bicycle
- Treadmill

Rate Pressure Product (Heart Rate x Systolic BP/100)

Target Heart Rate (Beats/Minute)
CHAPTER V

DISCUSSION

Results of this study indicated that SBP and RPP were greater in relation to heart rate during bicycling than during treadmill walking, arm cranking, or stationary rowing. Although the differences were small, they were statistically significant \((p < 0.01)\). Ranges of mean values for SBP were 122.3 to 127.1 mmHg at a target rate of 100, 132.3 to 142.5 mmHg at a target heart rate of 125 and 137.0 to 149.9 mmHg at a target heart rate of 150. RPP ranges were 123.3 to 130.2 at a target heart rate of 100, 166.3 to 182.0 at a target heart rate of 125 and 207.5 to 228.0 at a target heart rate of 150. Even though mean values of SBP and RPP were significantly higher during bicycling, the differences were quite small and probably not of clinical importance in exercise programming or exercise prescription.

No studies were found in the literature which were similar in design to the present study which compared SBP and RPP in relation to a given HR. In light of the results of several studies which have compared HR and SBP responses in relation to \(\dot{V}O_2\) during various types of exercise, however, the results of the present investigation are not entirely unexpected. The previous investigations have consistently demonstrated that both HR and SBP increase more markedly the smaller the relative amount of muscle mass which is involved in exercise. Astrand et al. (1965), Bevegård et al. (1966) and Stenberg et al. (1967) all found that HR and SBP increased linearly in relation to \(\dot{V}O_2\) during
arm cranking and bicycling but that both responses were significantly more pronounced during arm cranking. Hermanson et al. (1970) found that HR and SBP values were higher at comparable submaximal \( \dot{V}O_2 \) levels during bicycling than during treadmill running. An investigation done by Sawka et al. (1980) indicated that HR, SBP and RPP were all higher in relation to submaximal \( \dot{V}O_2 \) levels during wheel chair cranking than during arm cranking. Because both HR and SBP have been consistently demonstrated to be higher at given \( \dot{V}O_2 \) levels during exercise involving small muscle groups than during exercises using larger muscle groups, differences in SBP at given heart rates during arm versus leg exercise were expected to be small.

Why SBP and therefore RPP were higher in relation to HR during bicycling in the present study is not clear although possible explanations have been provided by the findings of earlier investigations. Faulkner et al. (1971) compared HR values after five and ten minutes of exercise at 90-95% of maximum \( \dot{V}O_2 \) during bicycling and treadmill running. During bicycling HR was found to increase significantly between the fifth and tenth minutes while during running there was no change over the same period of time. It appears likely that HR response lags behind SBP response during bicycling, and that the exercise bouts in the present study were too short to allow HR to reach a plateau level. If this is true, it is possible that HR values were falsely low during bicycling in the present study and that corresponding SBP values were falsely high. Possibly, if longer exercise bouts had been used, exercise intensities during bicycling would have had to be decreased to enable HRs to plateau at the
appropriate targets and SBP values would therefore have been lower. Results of an investigation done by Tuttle and Hovarth in 1957 may also provide a partial explanation for the elevated SBP and RPP responses in relation to HR during bicycling. They compared cardiovascular responses to isometric versus dynamic work. Dynamic work consisted of bicycling at 1250 kpm·min⁻¹ and the static work consisted of squeezing a hand dynamometer maximally for a one-minute period of time. Results of the study indicated that SBP increased similarly during both dynamic and isometric work but that the magnitude of the increase in HR during static work was smaller than during dynamic work. The SBP response in relation to HR would seem to be more pronounced during isometric work than during dynamic work. Most of the subjects in the present study were well conditioned and, as a result, relatively large workloads were needed to elicit the 125 and 150 target heart rates. When pedaling at high levels of resistance on the bicycle ergometer, it is likely that a good deal of isometric work may have been done with the hands and arms in an effort to stabilize the upper body and maximize the power generated with the legs. Thus, it is possible that a larger component of isometric work was involved in bicycling than in treadmill walking or dynamic arm work such as arm cranking or rowing, and that the SBP response in relation to HR was therefore more pronounced.

Results of the present study also indicated that SBP increases between target heart rates of 100 and 125 beats per minute and between 125 and 150 beats per minute were small and not statistically significant \( p > 0.01 \) while corresponding increases in RPP were significant \( p < 0.01 \). The overall mean values for SBP were 124.7, 135.6 and 141.7
mmHg for target heart rates of 100, 125 and 150 beats per minute, respectively. Overall means for RPP were 126.3, 171.9 and 214.5 for target heart rates of 100, 125 and 150 beats per minute, respectively. These values are in close agreement with those of a study done by Kitamura et al. (1972). The purpose of their investigation was to study the relationships between several easily measured hemodynamic variables and M\(\dot{V}O_2\). The researchers recorded mean SBP values during bicycling of 124 and 136 mmHg at heart rates of 104 and 145 beats per minute, respectively. Mean RPP values at those heart rates were 129 and 196. SBP values at similar heart rates in the present study were 124.7 and 141.7 mmHg and RPP values were 126.3 and 214.5. When correlation coefficients were calculated of M\(\dot{V}O_2\) with the various hemodynamic variables, the correlation of RPP with M\(\dot{V}O_2\) was highest (.90), HR with M\(\dot{V}O_2\) was nearly as high (.88) and SBP with M\(\dot{V}O_2\) was a good deal lower (.75). The researchers concluded that RPP was the best indicator of myocardial workload and that HR alone was also quite good. SBP alone was not concluded to be a good indicator of myocardial workload. The finding in the present study that SBP did not increase significantly between heart rates of 100 and 125 beats per minute or between 125 and 150 beats per minute while corresponding increases in RPP were significant seemed to substantiate their conclusions. SBP did not appear to be a good indicator of M\(\dot{V}O_2\). HR, on the other hand, appeared to be the primary determinant of M\(\dot{V}O_2\) as indirectly indicated by RPP.
CHAPTER VI
SUMMARY, CONCLUSIONS, CLINICAL IMPLICATIONS, AND RECOMMENDATIONS

Summary

Many phase II cardiac rehabilitation programs incorporate both arm and leg exercise in the rehabilitation process. For the sake of practicality, heart rate is usually used as the measure of exercise intensity during both arm and leg work. Because both heart rate and systolic blood pressure are major determinants of myocardial workload and because the onset of myocardial ischemia in cardiac patients is closely related to the level of $\dot{V}O_2$ as predicted by rate pressure product, a knowledge of the systolic blood pressure and rate pressure product responses in relation to heart rate during various types of phase II arm and leg exercise is important. The purpose of this study was to compare systolic blood pressure and rate pressure product values during arm versus leg exercise at pre-selected target heart rates.

Sixteen healthy male volunteers between twenty and thirty years of age participated in the study. Subjects performed three submaximal exercise sessions: one at each of three target heart rates. The target heart rates used were 100, 125 and 150 beats per minute. Arm cranking, stationary rowing, treadmill walking, and stationary bicycling were performed at each exercise session. Bouts of arm and leg exercise were performed in alternating order, and were separated by rest periods during which heart rates were allowed to return to near resting values.
Heart rate was determined from an electrocardiographic rhythm strip which was obtained during the last twenty seconds of each exercise bout. A standard cuff and sphygmomanometer were used to measure arterial blood pressure at the brachial artery within twenty seconds after the completion of exercise bouts. Rate pressure product was calculated by multiplying heart rate times systolic blood pressure and dividing the product by 100.

All data were analyzed using a two-way analysis of variance with repeated measures. The two-way analysis of variance consisted of three groupings for target heart rate and four groupings for exercise type. The Sheffé post hoc test was used when appropriate to analyze differences between paired means. The .01 level of confidence was selected to determine the significance of differences among mean values for all variables.

Conclusions

Within the limitations of the present study, the following conclusions were made:

1. There was a statistically significant increase \((p<0.01)\) in rate pressure product for each increase in target heart rate.

2. Both systolic blood pressure and rate pressure product were significantly higher \((p<0.01)\) at the selected heart rates during bicycling than during arm cranking, stationary rowing or treadmill walking.

3. There were no statistically significant differences \((p>0.01)\) in systolic blood pressure or in rate pressure product among arm cranking, stationary rowing or treadmill walking at selected heart rates.
4. Systolic blood pressure was significantly higher (p<0.01) at a target heart rate of 150 beats per minute than at a target heart rate of 100 beats per minute. There were no statistically significant differences (p>0.01) in systolic blood pressure between target heart rates of 100 and 125 beats per minute or between 125 and 150 beats per minute.

**Clinical Implications**

The finding that a statistically significant increase in rate pressure product accompanied each increase in target heart rate while corresponding increases in systolic blood pressure were not statistically significant indicates that heart rate was apparently the predominant component of myocardial work. Although systolic blood pressure and rate pressure product, in the present study, were both statistically greater in relation to heart rate during bicycling than during the other types of exercise, the differences were too small to be clinically important. Thus, heart rate is probably a safe and practical measure of exercise intensity for the four types of phase II exercise used in the present investigation. The findings of this study appear to refute concern about the safety of using dynamic arm exercise in phase II cardiac rehabilitation. Further study is needed, however, in order to determine if the findings of the present study apply to a population of CAD patients.

**Recommendations**

Based on the findings of the present study, the following future investigations might be helpful in adding to our growing knowledge:
1. A study could be conducted which is similar to the present study but cardiac patients should be used as subjects.

2. A study could be conducted in which each subject performs maximal exercise tests on a variety of arm and leg exercise modalities. Regression lines could then be calculated for heart rate versus systolic blood pressure for each exercise type. Such a study might help determine if the findings of the present study hold true over a wide range of moderate and strenuous exercise intensities.
REFERENCES


APPENDIX A

INFORMED CONSENT FORM
Project Title: Systolic blood pressure response at selected submaximal heart rates during arm versus leg exercise.

Principle Investigator: Charles M. Martin

INFORMED CONSENT

I, ______________________, being of sound mind and body, and ______ years of age, do hereby consent to participate in a series of three (3) exercise test sessions administered by the person named above. Each session will consist of exercise to a selected sub-maximal target heart rate on each of four (4) exercise devices — an arm crank ergometer, a treadmill, a bicycle ergometer, and a rowing machine — with three (3) minute recovery periods between exercise bouts. Throughout each testing session I will have a blood pressure cuff on my right arm and three (3) adhesive electrodes on my chest.

I understand that the purpose of these testing sessions is to investigate the relationship between blood pressure and heart rate responses during arm versus leg exercise of varying intensity. Heart rate measurements will be taken by means of a single lead electrocardiogram just prior to the conclusion of each exercise bout, and blood pressure readings will be taken by means of a standard cuff and sphygmomanometer immediately after the completion of each bout.

There does exist the possibility that certain adverse changes may occur during the testing sessions or soon afterwards. These include transient lightheadedness, fainting, muscle cramping, and an extremely slight chance of heart attack or sudden death. Every effort will be made to minimize these risks. If any abnormal changes are observed, the test will be terminated immediately. In addition, I realize that I may terminate the test at any time if I do not feel I can safely continue. I am aware that I may withdraw from this study at any time.

I have read the foregoing and understand it. I have been fully advised of the nature of the tests and the possible risks involved in them, and I do hereby voluntarily assume those risks. All questions that I have asked have been answered to my satisfaction.

Signed: ______________________ on this date ____________.

Witnessed by: ______________________ on this date ____________.
Name

Age

Height

Weight

Social Security Number

Date

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