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Variation in Systolic Blood Pressure Between Exercise Modes

By

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Variation in Systolic Blood Pressure between Exercise Modes

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Introduction: The purpose of this study was to determine if systolic blood pressure (SBP), and therefore rate pressure product (RPP = systolic blood pressure * heart rate) differences exist between treadmill, cycle, and arm exercise at fixed heart rate (HR) values. **Methods:** Twenty-three individuals free from risk (NRF), and thirty individuals with ≥ 2 primary risk factors for coronary artery disease (RF) maintained steady-state exercise (treadmill, cycling, and arm exercise) at a fixed HR (across modes) while SBP values were collected. Apriori planned comparisons ($\alpha = 0.05$) were used to evaluate within group treadmill vs. cycle and treadmill vs. arm exercise SBP differences as well as between group differences in treadmill vs. cycle and treadmill vs. arm exercise mean SBP changes. **Results:** SBP was significantly increased during cycle and arm exercise compared to walking in both NRF (cycle: 8 mmHg ± 9.8, $p<0.001$; arm: 7.6 mmHg ± 9.5, $p<0.001$) and RF (cycle: 14.4 mmHg ± 12.5, $p<0.001$; arm: 16.6 mmHg ± 11.3, $p<0.001$) groups. The RF group displayed a larger SBP mode response compared to the NRF group (treadmill vs. cycle, $p<0.05$; treadmill vs. arm, $p<0.01$). **Discussion:** Exercise training intensity prescribed to individuals with coronary artery disease is often based on data derived from clinical treadmill exercise tests. However, many individuals may choose alternative modes of exercise. **Conclusion:** Results of this study indicate that SBP, and therefore myocardial oxygen demand, are increased during cycling and arm exercise compared to walking. Prescribed exercise intensity may need to be lowered for individuals diagnosed with exertional angina and/or hypertension who choose to utilize these modes for regular exercise.

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Chapter One: Introduction

Introduction

It is common practice within the medical community to prescribe exercise training intensity for patients diagnosed with coronary artery disease (CAD) by using a percentage of maximal heart rate (HR) determined from a treadmill graded exercise test (GXT) (Froelicher, 1987; Howley and Franks, 1997; Miller, 1993). For patients who have not participated in a GXT, the Karvonen formula is often used to estimate an appropriate training heart rate (THR) range (Williams, 1999). Alternatively, rate of perceived exertion (RPE) is commonly used to determine exercise training intensity by asking patients to subjectively quantify the perceived difficulty of a specific workload (Williams, 1999).

It is currently widely accepted that CAD patients who exhibit exertional angina should avoid exercise intensities at or above their specific anginal threshold in order to avoid potential myocardial damage (Miller, 1993; Pollock and Wilmore, 1990; Williams, 1999). Two common recommendations for patients who experience angina are to exercise at five to ten beats/minute below, or between a HR of 70-85%, anginal threshold (Pollock and Wilmore, 1990). These recommendations however, cannot be applied to patients who suffer from non-symptomatic or silent angina and have not completed a GXT. Patients in this category cannot detect when they are experiencing angina due to lack of symptoms. As a result, a GXT is the most practical diagnostic method to determine the exercise intensity at which the anginal threshold occurs during exertion for these patients. It is important for patients with silent angina to strictly adhere to their prescribed THR range because of the risk of unknowingly exceeding their anginal threshold, which could lead to ischemic heart damage.

The most practical, non-invasive method to quantify anginal threshold is by estimating total heart work by measuring the product of HR and systolic blood pressure (SBP), which is termed rate pressure product (RPP) (Amsterdam and Mason, 1977). In 1977, Gobel, Nordstrom, Nelson, Jorgensen, and Wang found that the product of HR and systolic blood pressure (SBP) at a given workload correlated well with myocardial oxygen uptake in patients with CAD. The relatively simple method of estimating cardiac work by measuring RPP was found to be safer for patients who were previously subjected to catheterization to determine cardiac work (Robinson, 1967).

In a study of 15 patients with exertional angina, Robinson (1967) found that within individuals, episodes of angina occurred at similar RPP values even between different exercise modes, intensities, and durations. This important data made it clear that the onset of exertional angina was well correlated with the amount of work being placed specifically on the heart as measured by RPP. Alternatively, overall body work, as measured by $V0_2$ correlates poorly with the onset of exertional angina within individuals (Amsterdam and Mason, 1977; Robinson, 1967). Similarly, Noble (1982) observed that the onset of angina does not correlate well with RPE because patients appear to evaluate their effort independently of the angina. It is not uncommon for anginal patients to experience severe angina with an RPE not greater than nine or 10 (Noble, 1982).

It is important that health professionals encourage CAD patients to choose a favored mode of exercise (Miller, 1993) in order to facilitate adherence to regular training. However, if patients choose an alternative mode of exercise from that in which their anginal threshold was determined, certain problems may arise, especially when they are instructed and encouraged to maintain a specific pre-determined THR based on a previous GXT (Williams, 1999). As previously stated the vast majority of prescribed THR ranges are determined by the maximum HR or anginal threshold demonstrated exclusively on a treadmill. Since no studies to date have examined the differences in SBP at fixed HR values between exercise modes in individuals with ≥ 2 primary risk factors for CAD, it is possible that significant variances exist. This question becomes especially relevant when dealing with CAD patients who experience exertional angina, particularly silent angina.

Problem

This paper reports the results of two independently conducted, but related projects, evaluating SBP response at fixed HR values across exercise modes. The purpose of this study was to determine if any differences exist in SBP at fixed HR values between treadmill, cycle ergometer, and arm ergometer exercise both within and between multiple risk factor (RF) and non risk factor (NRF) groups.

Hypotheses

H_0: There will be no differences in SBP at fixed HR values between treadmill, cycle ergometer, and arm ergometer exercise either within or between RF and NRF groups.

H_R: SBP at fixed HR values will be increased both within and between RF and NRF groups during cycle and arm ergometer exercise compared to treadmill exercise.

Justification

To the best knowledge of the authors, no studies to date have examined the differences in SBP at fixed HR values between exercise modes using both subjects free from risk and individuals at risk for developing CAD.

Significance of the Study

It is critical that anginal patients exercise at intensities below anginal threshold in order to avoid possible myocardial damage (Miller, 1993; Pollock and Wilmore, 1990; Williams, 1999). If SBP values, and therefore RPP values, at a fixed HR do differ between exercise modes, these differences in myocardial oxygen demand should be accounted for when prescribing THR ranges for CAD patients. This may be particularly important for patients with silent angina who cannot symptomatically detect when anginal threshold is being exceeded. Results may also be valuable for those with resting/exercise hypertension who may be at risk of exceeding safe SBP levels during exercise.

Rationale of the Study

Only one study has examined the differences in SBP values at a fixed HR between exercise modes (Coplan, Gleim, Scandura, and Nicholas, 1987). However, this study compared exclusively treadmill versus arm ergometer exercise in young, healthy individuals. The current study included the addition of cycle ergometer testing as well as utilized individuals with ≥ 2 primary risk factors for developing CAD.

Limitations

i / non-randomized sample. The subjects in this study were not randomly selected.

ii / subject population. The results of this study are limited to individuals free from risk and those who have ≥ 2 risk factors for developing CAD.

iii / modes of exercise. The results of this study are limited to treadmill, cycle ergometer, and arm ergometer exercise.

iv / instrumentation. An inherent margin of error exists in the measurement of exercise BP values. Errors in exercise BP measurement were minimized by comparing arterial palpation (radial/brachial artery) of SBP with ausculatory measurements using two investigators to maximize reliability.

Delimitations

i / type of subjects. The results of this study may have implications concerning exercise prescription for individuals at risk of developing CAD.

ii / applicable intensity levels. A HR associated with individual subject perception of exertion was used to determine intensity levels for this study. The intensity levels used are similar to those chosen by patients during regular exercise training.

iii / applicable exercise modes. Treadmill walking, cycle ergometer, and arm ergometer exercise are all common modes of exercise used by CAD patients for rehabilitation purposes.

iv / randomized exercise testing order. Subjects exercised in a randomly assigned order for all testing.

Definition of Terms

Angina: chest pain caused by myocardial ischemia

Anginal threshold: the intensity level of physical exertion associated with the onset of angina

Graded exercise test (GXT): a stepwise incremental exercise test to maximum exertion often used to diagnose CAD and/or to determine functional aerobic capacity

Myocardial ischemia: inadequate oxygen supply to heart muscle tissue in order to meet metabolic needs

Rate of perceived exertion (RPE): subjective means of measuring individual exercise intensity levels determined by the Borg scale of perceived exertion (range of RPE = 6-20)

Rate pressure product (RPP): indirect measure of myocardial oxygen consumption (heart work) determined by the product of HR and SBP

Silent angina: myocardial ischemia without symptomatic anginal pain

Target/training heart rate (THR): individually prescribed heart rate range for aerobic exercise intensity often determined and prescribed by health professionals

Chapter Two: Literature Review

Treadmill and Cycle Ergometer Exercise

Many studies have been conducted examining differences in hemodynamic and myocardial ischemic response between treadmill and cycle ergometer exercise. Coplan, Sacknoff, Stachenfeld, and Gleim (1994) compared differences in hemodynamic response at 70% and 80% of predicted maximum HR between treadmill walking and cycling in young healthy males. Cycling resulted in significantly elevated SBP and RPP values at both intensities compared to treadmill exercise.

In a similar study using healthy college-age males, Hermansen, Ekblom, and Saltin (1970) found that maximal treadmill exercise resulted in significantly increased maximal cardiac output (CO) and maximal VO_2 values compared to cycling. Cycling however, resulted in higher sub-maximal HR values, maximal mean arterial pressures (MAP), and maximal total peripheral resistance (TPR). Hermansen et al. (1970) theorized that the elevated MAP and TPR values, which may have decreased stroke volume (SV), could explain the decreased CO values displayed during cycling exercise.

In a study using young college males, Miyamura and Honda (1972) found similar SV values with increased CO levels during treadmill exercise compared to cycling. However, in contrast to previous studies, maximal HR values were found to be lower during cycling than treadmill exercise. The investigators attributed the lower CO values to the decreased HR response demonstrated during cycling. In addition, AVO_2 difference was found to be significantly higher during treadmill exercise probably due to the increased muscle mass involved with uphill walking.

Yamakado, Kasai, Masuda, Futagami, Kawasaki, Zhang, and Nakano (1996) investigated hemodynamic differences between treadmill and cycling exercise in patients with vasospastic angina. Results showed maximum HR response was significantly higher on the treadmill, yet SBP was significantly increased on the cycle ergometer. RPP values were found to be similar at maximum exercise between the two exercise modes. Sub-maximal values were not reported in this investigation.

Hambrecht, Schuler, Muth, Grunze, Marburger, Niebauer, Methfessel, and Kubler (1992) examined male patients with diagnosed CAD and found that maximum HR values attained during treadmill exercise were significantly higher than cycling. However, in contrast to Yamakado et al. (1996), maximal RPP values were elevated with treadmill walking compared to cycling. Sub-maximal HR and RPP values were not reported in this study.

Klein, Cheo, Berman, and Rozanski (1994) studied patients with CAD and found similar HR responses, but significantly increased SBP, diastolic blood pressure (DBP), and RPP values during cycling compared to treadmill walking. Elevated DBP values during cycling compared to treadmill walking has been previously reported and may be due to greater force production per unit of muscle mass and therefore greater mechanical compression of blood vessels (Palatini, 1988). SBP elevations observed during cycling exercise may be caused by increased TPR resulting from the isometric hand-grip contraction often associated with this mode of exercise (Calvert, Pater, Pye, Mann, Chalmers, and Ayres, 1987).

Wetherbee, Bamrah, Ptacin, and Kalbfleisch (1988) studied the hemodynamic differences between patients with CAD and healthy subjects during treadmill and supine cycling exercise. Results showed significantly increased SBP levels in both groups at maximal exercise during cycling, but similar HR values in both modes of exercise at sub-maximal levels. Additionally, RPP values were similar between modes at maximal exercise, yet significantly elevated during cycling at similar (metabolic equivalents of oxygen consumption) sub-maximal intensities. A confounding variable in this study was that all treadmill testing was conducted in the morning and all cycle testing in the afternoon. Because significant variations in the hemodynamic response to exercise can occur throughout the day (Cohen and Muehl, 1977; Joy, Pollard, and Nunan, 1982; Pepine, 1991; Reilly, Robinson, and Minors, 1984; Saito, Matsubara, Yamanari, Uchida, Naotsugu, Mizou, Sato, Kobayashi, Maekawa, Fukushima, and Haraoka, 1993), caution must be taken when interpreting this data.

Arm Ergometer Exercise

Relatively few studies have compared the hemodynamic response of arm ergometry to other modes of exercise in patients with CAD. This is surprising considering many patients with this disease occupationally perform arm work, or individually choose to engage in arm exercise during leisure activities (Acker Jr. and Martin, 1988). Others use arm ergometry as their primary mode of rehab exercise as they cannot adequately maintain lower body exercise for effective rehabilitation due to orthopedic problems, claudication, or amputation (Acker Jr. and Martin, 1988). According to Franklin (1985), arm exercise should be emphasized in all cardiac rehabilitation programs in order to specifically train the muscles used for activities of daily life.

Differences in cardiovascular response between arm and leg exercise were examined in 51 male subjects with stable angina by Ben-Ari, Fisman, Pines, Shiner, Tavel, and Kellermann (1989). Various comparable sub-maximal workloads in incremental arm and leg exercise testing resulted in similar HR, SBP, and RPP responses among subjects.

In a similar study conducted by Schwade, Blomqvist, and Shapiro (1977), 33 male CAD patients were tested on a cycle and arm ergometer. At maximal exercise, significantly higher HR values were observed during cycling compared to arm exercise. No differences however, were found in RPP values at maximal exercise between the two modes.

In an investigation conducted by Coplan et al. (1987), subjects displayed higher SBP, oxygen consumption, and RPP values at 85% of predicted maximum HR on the treadmill compared to arm ergometry exercise. The increase in RPP resulting from treadmill exercise was due to the higher SBP levels elicited at the fixed HR value.

Acker Jr. and Martin (1988) compared hemodynamic variables between treadmill and arm ergometry exercise in 95 cardiac rehabilitation patients. HR, SBP, RPP, and ischemia were all significantly increased during maximal treadmill exercise versus arm ergometry.

However, contrary to the findings of Acker Jr. and Martin (1988), Franklin (1985) has reported that arm ergometry often results in increased HR, SBP, DBP, and RPP values at similar sub-maximal workloads compared to leg exercise. These increased hemodynamic variables during arm exercise may be due to a decreased mechanical efficiency or the smaller muscle mass recruitment associated with this type of exercise. Franklin (1985) has also reported lower observed SV levels during arm versus leg exercise at similar workloads. Decreased SV levels displayed during arm ergometry may increase sympathetic tone, which in turn may increase RPP values (Franklin, 1985). Vasoconstriction of the non-exercising leg muscles during arm work has also been cited as a possible mechanism to explain these observed RPP increases (Franklin, 1985).

Chapter Three: Methodology

Setting

All testing was conducted in The University of Montana Human Performance Laboratory, Department of Health and Human Performance, McGill Hall #121.

Subjects

Subjects consisted of 30 individuals with ≥ 2 primary risk factors for CAD (RF) and 23 individuals without any primary risk factors for CAD (NRF). Subjects for both groups were recruited from the University and local community. All subjects participated on a voluntary basis and completed a University Institutional Review Board-approved subject information and informed consent form prior to testing. Subject risk was minimized by the monitoring of symptoms and EKG recordings. An emergency medical technician was present during all testing. All testing was conducted at sub-maximal intensity levels (RPE $\leq$ 12).

Descriptive Data

Descriptive data collected and recorded included: gender, age, health history (PAR-Q and heart disease risk factor form), physical activity patterns (Health Insurance Plan of New York Activity Questionnaire), medication use, height (Narragansett Machine Co. Stadiometer), weight (Toledo weight scale), body mass index (BMI), resting HR (Quinton 4000 ECG recorder), and resting BP (Labtron Accumax cuff, 3M Littmann stethoscope).

Exercise Testing

Because two separate but related studies were conducted, slight differences existed in testing methodology between the NRF and RF groups. All subjects exercised on a treadmill (Quinton 4000, Seattle, WA), cycle ergometer (Monark 824 E, Varberg, Sweden), and arm ergometer (TRU-kinetics, Missouri City, TX) at similar times of day during one visit to the lab. Subjects in the NRF group began testing on the treadmill followed by randomly assigned cycle and arm exercise. Subjects in the RF group were randomly assigned to all three modes of exercise. The HR elicited at an RPE (Borg scale) of 10 (for the NRF group) or 12 (for the RF group) during the initial exercise bout served as the fixed HR for the remaining two modes. Exercise on each apparatus was initiated at a low intensity and was incrementally increased until the appropriate fixed HR was achieved. Adjustments were made to workloads in order to achieve a steady HR that fell within ±5 beats per minute of the desired HR. Once achieved, HR values were allowed to plateau for three minutes prior to exercise BP measurement according to Palatini (1988). Between each exercise testing bout, all subjects rested in a seated position for at least 10 minutes (according to Acker Jr. and Martin, 1988) to allow HR to return to within 10 beats per minute of baseline values. If necessary, a brief explanation and practice session was given on all exercise modes prior to testing. Each subject who participated in a practice session was required to rest quietly for five minutes prior to commencement of exercise testing.

Treadmill Testing

Subjects in the NRF group walked at a self-selected speed with gradual increases in grade until an RPE of 10 was achieved. Subjects in the RF group walked at a pace of 2.8 miles/hour with gradual increases in grade until either an RPE of 12 or the desired HR was achieved, depending on testing order. Workloads were then held constant to allow a five-minute HR plateau period. Subjects were required to lightly grip the treadmill bar with both hands during the entire testing period to control for the isometric hand gripping action between exercise modes. Subjects were asked to briefly release the grip of their right hand only during BP measurements.

Cycle Ergometer Testing

Subjects in both groups maintained a self-selected pedaling rate while resistance was gradually increased until either the desired RPE or HR was achieved, depending on testing order. Workloads were then held constant to allow a five-minute HR plateau period. During the plateau period, pedal rate was adjusted to maintain HR values within ±5 beats per minute of the desired value. Subjects were required to lightly grip the handlebars of the cycle ergometer with both hands during the entire testing period to control for the isometric hand gripping action between exercise modes. Subjects briefly released the grip of their right hand only when BP measurements were taken. Seat height and handlebar level were adjusted for each individual subject.

Arm Ergometer Testing

Subjects in both groups maintained a steady self-selected cranking rate while resistance was gradually increased until either the desired RPE or HR was achieved, depending on testing order. Workloads were then held constant to allow a five-minute HR plateau period. During the plateau period, cranking rate was adjusted to maintain HR values within ±5 beats per minute of the desired value. Subjects were required to continue cranking with one arm (at a decreased, but similarly perceived, resistance) during blood pressure measurement as previously described by Ben-Ari et al. (1989). Seat adjustments were made for each individual subject.

Blood Pressure Measurement

SBP and DBP were recorded at rest and during exercise (minutes three and five of HR plateau period) by manual ausculatory (Labtron Accumax cuff, Prescott, AZ; and 3M Littmann Stethoscope, St. Paul, MN) cuff sphygmomanometry according to Griffin, Robergs, and Heyward (1996) and Miller (1993). Previous research has determined that indirect methods of BP measurement provide reasonably comparable results to that of the direct intra-arterial method (Amsterdam and Mason, 1977), particularly during sub-maximal exercise (Palatini, 1988). Resting and exercise SBP values were also determined by manual palpation (radial/brachial artery) measurement techniques.

Heart Rate and EKG Monitoring

For NRF group subjects, HR values were obtained using a chest strap HR monitor (Polar HR monitor, Woodbury, NY). For RF group subjects, HR values were obtained by an EKG recording (Quinton 4000, Seattle, WA). HR values were recorded at rest and immediately prior to BP measurement for all modes of exercise. All RF subjects were continuously monitored (EKG leads I, II, III, AVF, AVR, AVL, and V5) during testing for arrhythmia, and ST abnormalities.

Exercise Test Termination Limits

Pre-determined testing termination limits included: sustained arrhythmia (≥3 consecutive premature atrial or ventricular beats), exercise-induced left bundle-branch block, ST deviation (≥2 mm ST depression or elevation), exercise SBP value ≥260 mmHg, exercise decrease in SBP with an increase in workload, exercise increase in DBP ≥15 mmHg, resting SBP value ≥200 mmHg, resting DBP value ≥115 mmHg, symptoms of painful angina, severe dyspnea, or dizziness (Kenney, 1995). No subjects were excluded for any of the above mentioned termination limits.

Dietary and Medication Control

Subjects were asked to abstain from food, alcohol, and caffeine consumption three hours prior to testing (Kenney, 1995). Additionally, subjects were instructed to wear appropriate exercise clothes and to avoid exercise for 24 hours prior to testing (Kenney, 1995).

PAR-Q, Heart Disease Risk Factor, and Physical Activity Pattern Questionaires

All subjects were asked to complete a PAR-Q, heart disease risk factor, and physical activity pattern (Health Insurance Plan of New York Activity Questionnaire) questionnaire prior to testing. See appendix for forms.

Statistical Procedures

Group differences for descriptive data were analyzed using independent student t-tests. An initial 2 (group) x 3 (mode), mixed design ANOVA was conducted to determine main effect differences between groups and exercise modes. A series of apriori planned comparisons were then used to evaluate within group treadmill vs. cycle and treadmill vs. arm exercise SBP differences (paired student t-tests). Independent student t-tests were used to evaluate between group (NRF vs. RF) differences in treadmill vs. cycle and treadmill vs. arm exercise mean SBP changes. An initial alpha value of 0.05 was used to determine statistical significance and was adjusted to 0.042 in order to adjust for the number of comparisons.

Chapter Four: Results

The RF group values for mean age, weight, BMI, resting SBP, and resting DBP were significantly higher ($p < 0.05$) than the NRF group. Group descriptive data are presented in Table 1.

Comparison of overall auscultation versus manual palpation SBP validity resulted in no significant differences between the two methods ($p = 0.27$). Auscultation and palpation SBP values were also highly correlated ($r = 0.89$), with a mean coefficient of variation of 0.04 ± 0.03.

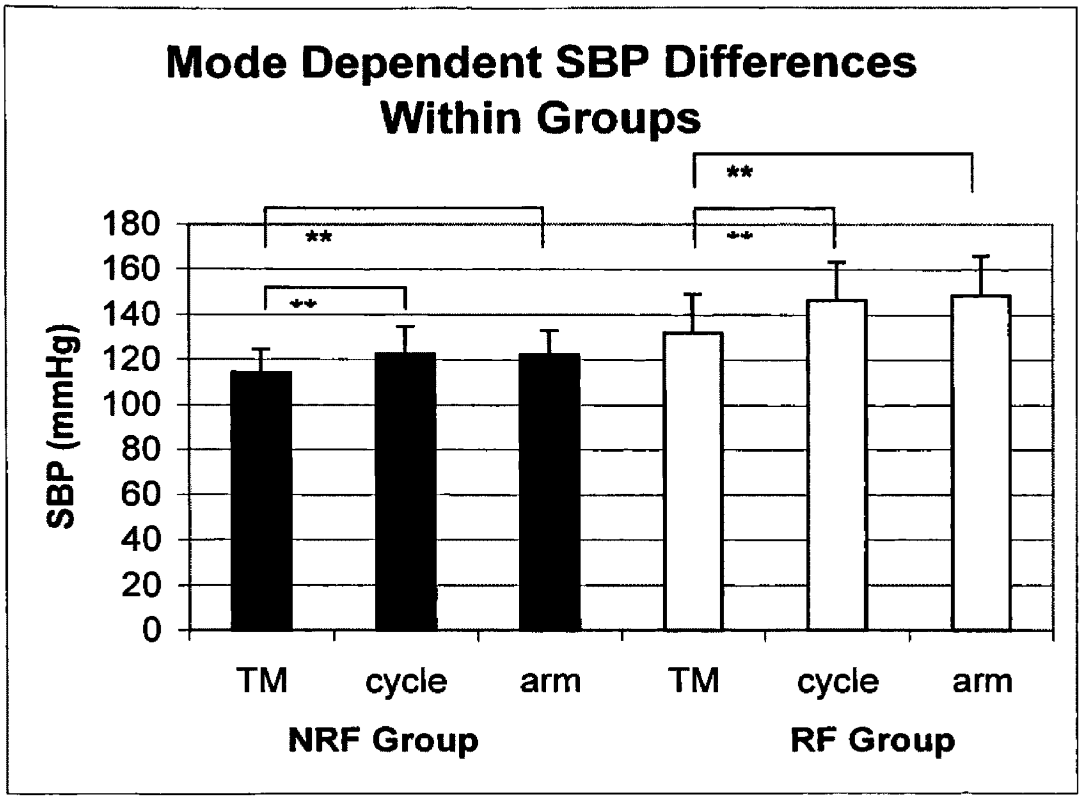
ANOVA resulted in significant main effect differences ($p < 0.05$) between groups and exercise modes. When compared to treadmill walking, SBP values were significantly increased within the NRF group during cycle (8 mmHg $\pm$ 9.8, $p < 0.001$) and arm (7.6 mmHg $\pm$ 9.5, $p < 0.001$) exercise and within the RF group during cycle (14.4 mmHg $\pm$ 12.5, $p < 0.001$) and arm (16.6 mmHg $\pm$ 11.3, $p < 0.001$) exercise. The RF group had a larger SBP mode response compared to the NRF group (treadmill vs. cycle, $p < 0.042$; treadmill vs. arm, $p < 0.01$). Figures 1. and 2. display within and between group results.

Table 1. – Subject Descriptive Data

	age	height	weight	BMI	HR rest	SBP rest	DBP rest
mean (NRF)	26.9±10.2	175.6±8.4	71.4±11.1	23.0±2.4	68.3±12.4	106.5±8.3	62.8±15.4
mean (RF)	*49.4±5.5	173.3±8.3	*80.8±18.0	*26.8±5.4	63.8±11.2	*118.4±16.0	*75.1±8.9

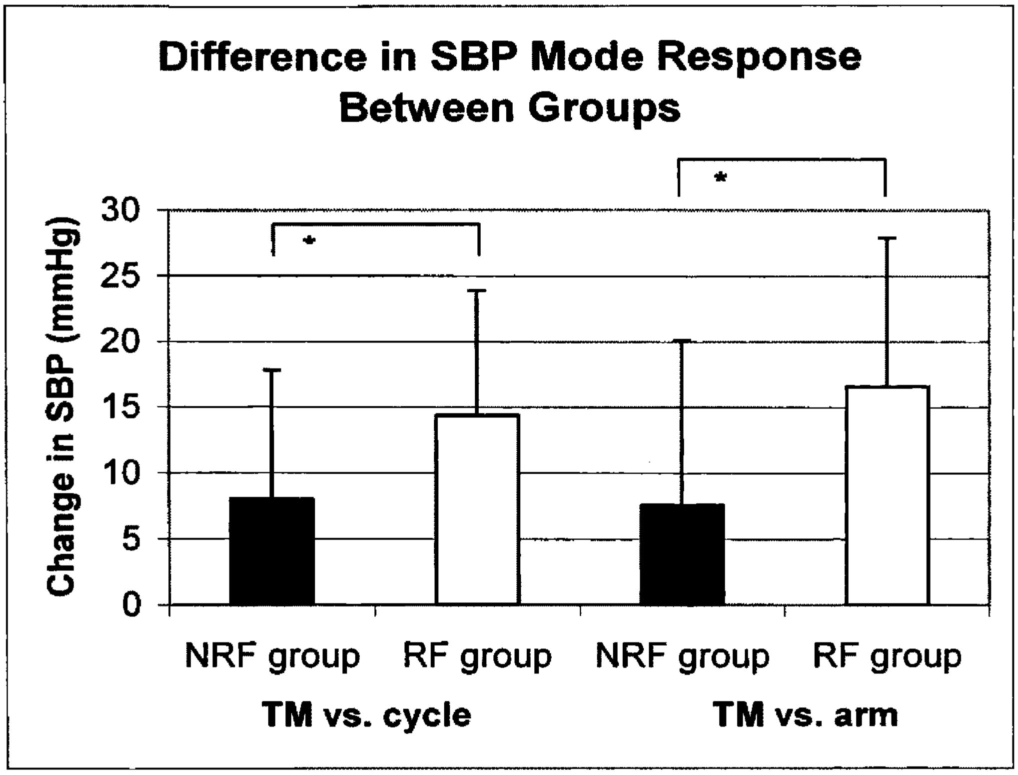
* significant difference between groups ($p < 0.05$)

Figure 1.



** significant difference between modes ($p < 0.001$)

Figure 2.



* significant difference between groups ($p < 0.05$)

Chapter Five: Discussion/Conclusion

Comparisons to Previous Research

Results of this study indicate that SBP values, and therefore RPP, are increased during cycling and arm exercise compared to treadmill walking when HR values are similar across exercise modes. In addition, it seems that individuals with ≥ 2 CAD risk factors are subject to a relatively greater SBP reactivity (larger increase in SBP and therefore RPP) between treadmill vs. cycle and arm exercise compared to individuals free from risk factors.

The increased SBP values during cycle vs. treadmill exercise observed in our study are similar to those reported by Coplan et al. (1994), Yamakado et al. (1996), Klein et al. (1994), Calvert et al. (1987), and Wetherbee et al. (1988). However, the elevated SBP displayed by our subjects during arm compared to treadmill exercise are contrary to the previous findings of Coplan et al. (1987) who reported the opposite occurrence. Certain methodological differences between the studies may explain the discrepancy in results. Coplan et al. (1987) required subjects to completely cease arm cranking for 30 seconds, while we required subjects to continue cranking with one arm (at a reduced resistance) during SBP measurement. We chose our arm exercise SBP measurement methodology based on information provided by Hollingsworth et al. (1990) who reported that SBP measured immediately *after* arm exercise significantly underestimated actual SBP obtained *during* exercise. In addition, our subjects exercised at a relatively lower intensity compared to those in the study conducted by Coplan et al. (1987).

Factors Affecting Exercise Blood Pressure

The different SBP responses between treadmill, cycle, and arm exercise were likely affected by many factors. Previously, Franklin (1985) suggested that the decreased mechanical efficiency often associated with arm ergometry could increase SBP compared to various types of leg exercise. In addition, Franklin (1985) and Coplan et al. (1994) have reported that arm and cycle exercise often result in decreased stroke volume (SV) compared to treadmill walking exercise. Results from our study indicate that increased afterload (due to increases in SBP) may contribute to these lower observed SV levels previously reported. Another possible explanation for the changes in SV associated with these exercise modes may be a decreased preload or end-diastolic volume (EDV). EDV is affected by venous return, which is likely lower during arm and cycle exercise at least partially due to a decrease in the "blood pumping action" of contracting skeletal muscle (due to the decrease in recruited muscle mass). The decreased amount of muscle mass utilized during arm and cycle exercise also decreases peripheral vasodilation, which potentially may contribute to an increase in TPR and therefore SBP. Lastly, Franklin (1985) has suggested that non-exercising muscle during arm exercise may exert an exaggerated vasoconstrictive response further elevating SBP values.

Although not evaluated in our study, another suggested factor possibly contributing to SBP differences during arm exercise may be a decrease in vagal stimulation (Tulppo, Makikallio, Laukkanen, and Huikuri, 1999), which would cause an increase in both HR and BP. Additionally, the isometric hand-grip associated with arm cranking may have influenced SBP values. Although subjects were asked to lightly hold the treadmill and cycle bar to control for this factor, it is likely that subjects maintained a tighter grip during arm exercise compared to cycling and walking due to the nature of arm cranking.

Many factors may have contributed to the increased SBP reactivity response observed in the RF group including the perceived intensity of work or differences in subject characteristics between groups. It is difficult to isolate whether the reactivity was due to the slightly higher perceived intensity used in the RF compared to the NRF group, and/or the differing subject characteristics including age, weight, BMI, resting SBP, and resting DBP values between groups. The RF group exercised at a relatively higher intensity (mean fixed HR = 115.3 ± 11.3) compared to the NRF group (mean fixed HR = 100.4 ± 18.5). It is therefore possible that a larger percentage of the RF group may have been exercising above their anaerobic threshold during arm and cycle exercise while maintaining a workload below this level during treadmill walking since threshold levels tend to differ between modes of exercise. Previous research has shown that SBP, HR, and RPP tend to increase in a non-linear fashion at exercise intensities above the anaerobic threshold (Spence et al., 1987 and Tanaka et al., 1997). The exaggerated increase in these variables are likely due to the elevated levels of circulating catecholamines and increased sympathetic nervous activity that are associated with exercise intensities above the anaerobic threshold. Interestingly, Spence et al. (1987) have reported that hypertensive individuals tend to display greater plasma catecholamine levels at the onset of blood lactate accumulation compared to untrained normotensive individuals at the same level of lactate accumulation. Therefore, our results may have implications for hypertensive individuals who may elicit even further exaggerated increases in SBP than was observed in our RF group.

Exercise Hypertension and Silent Ischemia

Recent investigations have shown an increased occurrence of silent or non-symptomatic ischemia associated with resting and exercise hypertension (Krittayaphong and Sheps, 1996; Go, Sheffield, Krittayaphong, Maixner, and Sheps, 1997; and Klein et al., 1994). In particular, Go et al. (1997) found that acute, large increases in exercise BP as well as elevated SBP levels at the onset of ischemia, tended to decrease anginal pain perception in CAD patients. Furthermore, Klein et al. (1994) reported silent angina to be three times more prevalent during cycling compared to treadmill exercise. Data from our study suggest that because SBP values seem to be elevated during cycle and arm exercise at fixed HR values, individuals with angina who engage in these activities may be more likely to experience silent ischemia. Additionally, results from the current study demonstrate an elevated SBP response during cycling, possibly suggesting that this may be a mechanism responsible for the occurrence of the hypertension-related hypoalgesia as reported by Klein et al. (1994).

Implications of Results

Although our study population consisted of individuals free from CAD, it is possible that angina patients would elicit similar, if not exaggerated exercise SBP responses to those in our study. Because our study demonstrated that individuals with $\geq$ 2 risk factors elicited exaggerated SBP responses compared to individuals free of risk, it is logical to consider the possibility that individuals with additional risk factors, or those with CAD may display a similar, if not further exaggerated response. It is therefore important to consider these results in lieu of the potential impact it may have on this group during exercise.

In order to prevent myocardial damage, it is critical for angina patients to avoid exercise intensities that exceed anginal threshold. Because data from our study suggest that SBP, and therefore stress placed on the heart, is elevated during cycle and arm activity, exertion levels prescribed as THR ranges from treadmill GXT data may be inappropriate for individuals who regularly engage in cycle and arm exercise. Walking may be a safer, and therefore more effective form of exercise for angina patients compared to cycling and arm ergometry because it places the least amount of strain on the heart at a comparable sub-maximal HR.

The results of this study are not only important for individuals diagnosed with silent angina, but also those with painful/symptomatic angina. These individuals who engage in cycle and arm exercise may fail to recognize when anginal threshold has been exceeded due to a blunted symptomatic perception of angina pain resulting from an acute elevation in SBP. Both physician and patient need to be aware of the potential implications of engaging in activities that may stimulate this response.

Study results may also apply to individuals diagnosed with resting or exercise hypertension. Hypertensive individuals should be made aware that cycling and arm exercise may result in exaggerated exercise blood pressure levels. Absolute exercise SBP values may need to be monitored periodically to ensure the maintenance of safe levels.

Conclusions

Results from our study indicate that cycle and arm ergometer exercise may place more stress on the heart at a similar HR compared to treadmill walking. Therefore, it may be wise for physicians and health professionals to lower prescribed THR's (derived from treadmill GXT data), or to utilize mode specific testing, for angina patients who regularly engage in cycle and arm exercise. In addition, patients with angina should be informed that these activities may place an increased workload on the heart and additional mode specific monitoring may be warranted. Additional mode specific SBP monitoring may also be useful for hypertensive individuals who may elicit elevated values during cycle and arm exercise compared to treadmill walking. Further research is warranted utilizing a population of hypertensive and angina patients. This will allow us to investigate the possible further exaggerated mode specific differences in exercise SBP values. Future investigations may also be directed at testing other popular exercise modes such as stair-climbing, swimming, rowing, etc. It may also be valuable to elucidate the underlying mechanism responsible for the observed SBP differences between exercise modes.

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Appendix

Attachments: Informed Consent Form, PAR-Q Form, Physical Activity Questionnaire, Risk Factor Assessment Form, Data Sheet

Subject Information and Consent Form

Human Performance Laboratory
Dept. of Health and Human Performance
McGill Hall
The University of Montana
Missoula, MT 59812

Title: Variation in Rate Pressure Product between Exercise Modes

Investigators: Steven E. Gaskill, Ph.D., McGill Hall, 243-4268
Aaron S. Kelly, McGill Hall, 243-5528
Brent C. Ruby, Ph.D., McGill Hall, 243-2117

Special Instructions to the Potential Subject:

- This consent form may contain words that are unfamiliar to you. Please feel free to ask any questions about the following material.

Purpose:

- You are being asked to participate in a research study comparing the heart rate and blood pressure response to different modes of exercise (cycling, walking, and arm crank exercise).
- You have been chosen because you are either 1) between age 40-60 years old and have 2-4 risk factors for coronary artery disease, 2) considered at high risk of developing this condition by a physician, or 3) diagnosed with coronary artery disease by a physician.
- The purpose of this study is to determine if any differences exist in the amount of heart work required by various modes of exercise (walking, biking, or arm crank exercise) at similar low-intensity heart rate values.

Procedures:

- If you agree to participate in this research study you will be asked to complete three bouts of low-intensity exercise (approximately 10-15 minutes each) on a treadmill, bike, and an arm cranking machine.
- Your blood pressure, EKG, and heart rate response will be monitored throughout each bout of exercise.
- A rest period of approximately 10-15 minutes will separate each exercise bout in order to allow blood pressure and heart rate values to return to near normal levels.
- Total test time will be approximately one hour during one visit to the lab.

Risks/Discomforts:

- Although physical activity is accompanied by only minimal risk in a healthy population, increased risk of experiencing a heart-related event (chest pain, heart rhythm abnormalities, heart attack, etc.) above that of a healthy population will exist during testing. Risk will be higher because you are either diagnosed with, or at increased risk of developing coronary artery disease.

- Mild overall physical discomfort may occur due to the low level of exertion during each exercise bout.
- All testing will be conducted at a low level of activity and exertion.
- You will be asked periodically during the testing to report any unusual symptoms. Unusual symptoms may include: undue shortness of breath, chest/jaw/arm/shoulder/upper back pain, dizziness, or any discomfort that differs from your normal exercise experience.

Precautions Taken to Decrease Risk to Subjects:

- An automatic defibrillator machine will be present during all testing.
- Defibrillator and CPR trained individuals will be present during all testing.
- EKG will be monitored continuously during all exercise and recovery periods.
- University of Montana Health and Human Performance research lab emergency procedures will be followed if an emergency situation were to arise.
- Physician approval for your participation will be obtained prior to testing if you have known or suspected coronary artery disease.

Benefits:

- Although no direct benefit may apply to you, your participation in this study may aid health professionals (physicians, nurses, exercise physiologists, cardiac rehab specialists, etc.) in designing and prescribing safer and more efficient exercise training intensities for patients with coronary artery disease.

Confidentiality:

- Your identity will be kept confidential.
- If the results of this study are written in a scientific journal or presented at a scientific meeting, your name will not be used.

Compensation for Injury:

Although we believe that the risk of taking part in this study is minimal, the following liability statement is required in all University of Montana consent forms.

In the event that you are injured as a result of this research you should individually seek appropriate medical treatment. If the injury is caused by the negligence of the University or any of its employees, you may be entitled to reimbursement or compensation pursuant to the Comprehensive State Insurance Plan established by the Department of Administration under the authority of M.C.A., Title2, Chapter 9. In the event of a claim for such injury, further information may be obtained from the University's Claims representative or University Legal Counsel. *(Reviewed by University Legal Counsel, July 6, 1993)*

Voluntary Participation/Withdrawal:

- Your decision to participate in this research study is entirely voluntary.
- You may withdraw from participation at any time without penalty.
- You may be asked to discontinue participation in the study if you fail to follow the instructions of the study director or if the study director believes it is in the best interest of your health and welfare.

Questions:

• If you have any questions concerning this research study contact: Steven Gaskill, Ph.D., (243-4268) or Aaron Kelly (243-5528) at The University of Montana Department of Health and Human Performance.

• If you have any questions regarding your rights as a research subject, you may contact the Institutional Review Board through the Research Office at The University of Montana at 406-243-6670.

Subject Statement of Consent:

I have read the above description of this research study. I have been informed of the risks and benefits involved, and all my questions have been answered to my satisfaction. Furthermore, I have been assured that any future questions may be directed to a member of the research team. I voluntarily agree to participate in this study. I understand I will receive a copy of this consent form.

____

Name of subject (print)

________________________________ ______________

Subject signature Date

________________________________ ______________

Signature of witness Date

Date Approved by UM IRB Nov 13, 2000

Approval Expires on Nov 12, 2001

[signature], IRB Chair

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 1994)

PAR - Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2. Do you feel pain in your chest when you do physical activity?
☐	☐	3. In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7. Do you know of any other reason why you should not do physical activity?

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want—as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active—begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal—this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever—wait until you feel better; or
- if you are or may be pregnant—talk to your doctor before you start becoming more active.

[illegible]

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

You are encouraged to copy the PAR-Q but only if you use the entire form.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

NAME ______________________

SIGNATURE ______________________ DATE ______________________

SIGNATURE OF PARENT ______________________ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

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Société canadienne de physiologie de l'exercice

Supported by: Health Canada / Santé Canada

Health Insurance Plan of New York Questionnaire

Physical Activity Connected with Job

Question	Answer	Assigned weight
Time on job spent sitting	Practically all	0
	More than 1/2	1
	About 1/2	2
	Less than 1/2	3
	Almost none	4
Time on job spent walking	Almost none	0
	Less than 1/2	1
	About 1/2	2
	More than 1/2	3
	Practically all	4
Walking to get to and from work	None or less than 1 block	0
	1 or 2 blocks	1
	3 or 4 blocks	2
	5 to 9 blocks	3
	10 to 19 blocks	4
	20 to 39 blocks (1 mile, not 2)	5
	40+ blocks (2+ miles)	6
Lifting or carrying heavy things	Very infrequently or never	0
	Sometimes	3
	Frequently	6
Transportation to and from work	None	0
	Car and/or bus and/or railroad and/or ferry	1
	Subway	2
	Subway and one or more other modes of transportation	3
Hours on the job	Less than 25	0
	25-34	1
	35-40	2
	41-50	3
	51+	4

Physical Activity Off the Job

Item	Frequently	Sometimes	Very infrequently or never
Takes walks in good weather	2	1	0
Works around house or apartment	2	1	0
Gardening in spring or summer	2	1	0
Takes part in sports			
Active ball game other than golf, bowling, pool or billiards is mentioned	4	3	0
Other	3	2	0

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RISK FACTORS SCREENING BATTERY FOR CORONARY HEART DISEASE

Name______________________________ Date________________

Age__________ Gender________ Please answer questions to the best of your knowledge.

1. Has anyone in your family (parents, siblings, grandparents, aunts and uncles) died suddenly of unknown cause? Yes No
   If Yes please give relationship, gender, and approximate age at death.

Relationship	Gender	Age at death

2. Does anyone in your family (parents, siblings, grandparents, aunts and uncles) have known coronary heart disease or had a heart attack? Yes No
   If Yes please give relationship, gender, and approximate age at event.

Relationship	Gender	Age at event

3. Have you ever been diagnosed with high blood pressure? Yes No
   Do you know what your last blood pressure measurement was?_____/_____
   Are you on medication for high blood pressure? Yes No
   If Yes, what medication(s)____________________________

4. Have you even been diagnosed with high cholesterol? Yes No
   Do you know what your last cholesterol measurements were?
   Total_____ LDL_____ HDL_____
   Are you on medication to control your cholesterol? Yes No
   If Yes, what medication(s)____________________________

5. Do you exercise (walking or higher intensity) at least 30 minutes daily? Yes No

6. Do you smoke currently or in the past 6 months? Yes No
   If Yes, how many cigarettes per day do you (or did you) smoke?__________

7. Do you have diabetes? Yes No
   If Yes, Type I or Type II and what year diagnosed?__________________

8. What is your height________(inches) and weight (lbs)__________

9. What is your waist size?_________(inches)

Data Sheet

"Variation of RPP between Exercise Modes"

Room Temp.: 19.5 °C Testing Start Time: 1:45 pm

Subject #: 1
Gender: F
Age: 24
Height: 67" (170.18)
Weight: 159.5 lbs (72.5)
BMI: 25

Medications: oral contraceptive

Resting HR: 73
Resting BP: 105 / 75

Exercise Mode # 1: Arm ergometer
RPE: 10
HR Elicited at RPE: 93
Minute 3 HR: 93
Minute 3 Auscultation BP: 110 / 70 Minute 3 Palpation SBP: 110
Minute 5 HR: 96
Minute 5 Auscultation BP: 107 / 70 Minute 5 Palpation SBP: 105
Average HR:
Average SBP: 108

10044

Exercise Mode # 2: Cycle ergometer
Minute 3 HR: 96
Minute 3 Auscultation BP: 100 / 70 Minute 3 Palpation SBP: 105
Minute 5 HR: 96
Minute 5 Auscultation BP: 100 / 70 Minute 5 Palpation SBP: 100
Average HR:
Average SBP: 101.25

9416.25

Exercise Mode # 3: Treadmill
Minute 3 HR: 93
Minute 3 Auscultation BP: 100 / 70 Minute 3 Palpation SBP: 100
Minute 5 HR: 91
Minute 5 Auscultation BP: 100 / 68 Minute 5 Palpation SBP: 98
Average HR:
Average SBP: 99.5

9253.5

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Number of tables - 1

Variation in Systolic Blood Pressure Between Exercise Modes

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Running Title: Mode Variations in Blood Pressure

ABSTRACT

Background: The purpose of this study was to determine if systolic blood pressure (SBP), and therefore rate pressure product (RPP = systolic blood pressure * heart rate) differences exist between treadmill, cycle, and arm exercise at fixed heart rate (HR) values. **Methods:** Thirty individuals with ≥ 2 primary risk factors for coronary artery disease (RF), and twenty-three risk free individuals (NRF) maintained steady-state exercise (treadmill, cycling, and arm exercise) at a fixed HR (across modes) while SBP values were collected. Apriori planned comparisons ($\alpha = 0.05$) were used to evaluate within group treadmill vs. cycle and treadmill vs. arm exercise SBP differences as well as between group differences in treadmill vs. cycle and treadmill vs. arm exercise mean SBP changes. **Results:** SBP was significantly increased during cycle and arm exercise compared to walking in both NRF (cycle: 8 mmHg ± 9.8, $p<0.001$; arm: 7.6 mmHg ± 9.5, $p<0.001$) and RF (cycle: 14.4 mmHg ± 12.5, $p<0.001$; arm: 16.6 mmHg ± 11.3, $p<0.001$) groups. The RF group displayed a larger SBP mode response compared to the NRF group (treadmill vs. cycle, $p<0.05$; treadmill vs. arm, $p<0.01$). **Conclusion:** Exercise training intensity prescribed to individuals with coronary artery disease is often based on data derived from clinical treadmill exercise tests. However, many individuals may choose alternative modes of exercise. Results of this study indicate that SBP, and therefore myocardial oxygen demand, are increased during cycling and arm exercise compared to walking. Prescribed exercise intensity may need to be lowered for individuals diagnosed with exertional angina and/or hypertension who choose to utilize these modes for regular exercise.

Key Words: exercise, blood pressure, rate pressure product

INTRODUCTION

It is common practice within the medical community to prescribe exercise training intensity for patients diagnosed with coronary artery disease (CAD) by using a percentage of maximal heart rate (HR) determined from a treadmill graded exercise test (GXT).[1-3] For patients who have not participated in a GXT, the Karvonen formula is often used to estimate an appropriate training heart rate (THR) range.[4]

It is currently widely accepted that CAD patients who exhibit exertional angina should avoid exercise intensities at or above their specific anginal threshold in order to avoid potential myocardial damage.[3-5] Two common recommendations for patients who experience angina are to exercise at five to ten beats/minute below, or between a HR of 70-85%, anginal threshold.[5] Similarly, it is important for individuals diagnosed with resting and/or exercise hypertension to avoid exercise intensities which can potentially result in dangerously elevated blood pressure levels. Hypertensive individuals, like those with exertional angina, often use a THR range to quantify effort during exercise training.

The most practical, non-invasive method to quantify anginal threshold is by estimating total heart work by measuring the product of HR and systolic blood pressure (SBP), which is termed rate pressure product (RPP).[6] In 1977, Gobel et al.[7] found that the RPP at a given workload correlated well with myocardial oxygen uptake in patients with CAD. Within individuals, episodes of angina have been shown to occur at similar RPP values even between different exercise modes, intensities, and durations.[8] These data suggest that the onset of exertional angina is well correlated with the amount of work placed specifically on the heart as measured by RPP.

Presently, little research has been conducted examining differences in SBP response at fixed HR values during exercise utilizing various modes of activity. In a previous study by Coplan et al.[9], differences in hemodynamic response at 70% and 80% of predicted maximum HR were evaluated between treadmill walking and cycling in young healthy males. Cycling resulted in significantly elevated SBP and RPP values at both intensities compared to treadmill exercise.

In a similar investigation conduted by Coplan et al.[10], subjects displayed higher SBP, oxygen consumption, and RPP values at 85% of predicted maximum HR on the treadmill compared to arm ergometry exercise.

It is important that health professionals encourage CAD patients to choose a favored mode of exercise[3] in order to facilitate adherence to regular training. However, if patients choose an alternative mode of exercise from that in which their anginal threshold was determined, certain problems may arise, especially when they are instructed and encouraged to maintain a specific pre-determined THR based on a previous GXT.[4] To the best knowledge of the authors, no studies to date have examined the differences in SBP at fixed HR values between exercise modes using both healthy subjects and individuals at risk for developing CAD. This paper reports the results of two independently conducted, but related projects, evaluating SBP response at fixed HR values across exercise modes. The purpose of this study was to determine if differences exist in SBP at fixed HR values between treadmill, cycle ergometer, and arm ergometer exercise both within and between multiple risk factor (RF) and non-risk factor (NRF) groups.

METHODS

Study Population

Subjects consisted of 30 individuals (males = 14, females = 16) with ≥ 2 primary risk factors for CAD (RF) and 23 individuals (males = 10, females = 13) without any primary risk factors for CAD (NRF). No subjects from either group were currently using any medication that may have affected HR or blood pressure. Subjects for both groups were recruited from the University and local community. All subjects participated on a voluntary basis and completed a University Institutional Review Board-approved subject information and informed consent form prior to testing.

Exercise Testing

Because two separate but related studies were conducted, slight differences existed in testing methodology between the NRF and RF groups. All subjects exercised on a treadmill (Quinton 4000, Seattle, WA), cycle ergometer (Monark 824 E, Varberg, Sweden), and arm ergometer (TRU-kinetics, Missouri City, TX) at similar times of day during one visit to the lab. Subjects in the NRF group began testing on the treadmill followed by randomly assigned cycle and arm exercise. Subjects in the RF group were randomly assigned to all three modes of exercise. The HR elicited at an RPE (Borg scale) of 10 (for the NRF group) or 12 (for the RF group) during the initial exercise bout served as the fixed HR for the remaining two modes. Exercise on each apparatus was initiated at a low intensity and was incrementally increased until the appropriate fixed HR was achieved. Adjustments were made to workloads in order to achieve a steady HR that fell within ±5 beats per minute of the desired HR. Once achieved, HR values were allowed to plateau for three minutes prior to exercise BP measurement according to methods described by Palatini.[11] Between each exercise testing bout, all subjects rested in a seated position for at least 10 minutes (as previously reported by Acker Jr. and Martin)[12] to allow HR to return to within 10 beats per minute of the resting value.

Treadmill Protocol

Subjects in the NRF group walked at a self-selected speed with gradual increases in grade until an RPE of 10 was achieved. Subjects in the RF group walked at a pace of 2.8 miles/hour with gradual increases in grade until either an RPE of 12 or the desired HR was achieved, depending on testing order. Subjects were required to lightly grip the treadmill bar with both hands during the entire testing period to control for the isometric hand gripping action between exercise modes. Subjects were asked to briefly release the grip of their right hand only during BP measurements.

Cycle Ergometer Protocol

Subjects in both groups maintained a self-selected pedaling rate while resistance was gradually increased until either the desired RPE or HR was achieved, depending on testing order. Subject hand grip (on cycle bar) and blood pressure procedures were followed as described for treadmill testing. Seat height and handlebar level were adjusted for each individual subject.

Arm Ergometer Protocol

Subjects in both groups maintained a steady self-selected cranking rate while resistance was gradually increased until either the desired RPE or HR was achieved, depending on testing order. Subjects were required to continue cranking with one arm (at a decreased absolute, but similarly perceived, resistance) during blood pressure measurement as previously described by Ben-Ari et al.[13] Seat adjustments were made for each individual subject.

Blood Pressure Measurement

SBP and DBP were recorded at rest and during exercise (minutes three and five of HR plateau period) by manual ausculatory (Labtron Accumax cuff, Prescott, AZ; and 3M Littmann Stethoscope, St. Paul, MN) cuff sphygmomanometry according to previously determined methods.[3,14] Resting and exercise SBP values were also determined by manual palpation (radial/brachial artery) measurement techniques. The auscultation and manual palpation SBP values collected during minutes three and five of exercise were averaged to determine a mean SBP value for each exercise mode.

Heart Rate and ECG Monitoring

For NRF group subjects, HR values were obtained using a chest strap HR monitor (Polar HR monitor, Woodbury, NY). For RF group subjects, HR values were obtained by an EKG recording (Quinton 4000, Seattle, WA). HR values were recorded at rest and immediately prior to BP measurement for all modes of exercise.

Statistical Procedures

Group differences for descriptive data were analyzed using independent student t-tests. An initial 2 (group) x 3 (mode), mixed design ANOVA was conducted to determine main effect differences between groups and exercise modes. A series of apriori planned comparisons were then used to evaluate within group treadmill vs. cycle and treadmill vs. arm exercise SBP differences (paired student t-tests). Independent student t-tests were used to evaluate between group (NRF vs. RF) differences in treadmill vs. cycle and treadmill vs. arm exercise mean SBP changes. An initial alpha value of 0.05 was used to determine statistical significance and was adjusted to 0.042 in order to adjust for the number of comparisons.

RESULTS

The RF group values for mean age, weight, BMI, resting SBP, and resting DBP were significantly higher ($p < 0.05$) than the NRF group. Group descriptive data are presented in Table 1.

Comparison of overall auscultation versus manual palpation SBP validity resulted in no significant differences between the two methods ($p = 0.27$). Auscultation and palpation SBP values were also highly correlated ($r = 0.89$), with a mean coefficient of variation of 0.04 ± 0.03.

ANOVA resulted in significant main effect differences ($p < 0.05$) between groups and exercise modes. When compared to treadmill walking, SBP values were significantly increased within the NRF group during cycle (8 mmHg ± 9.8, $p < 0.001$) and arm (7.6 mmHg ± 9.5, $p < 0.001$) exercise and within the RF group during cycle (14.4 mmHg ± 12.5, $p < 0.001$) and arm (16.6 mmHg ± 11.3, $p < 0.001$) exercise. The RF group had a larger SBP mode response compared to the NRF group (treadmill vs. cycle, $p < 0.042$; treadmill vs. arm, $p < 0.01$). NRF and RF group exercise data are shown in figures 1. and 2.

Table 1. – Subject Descriptive Data for Non-Risk Factor and Risk Factor Groups

	age	height	weight	BMI	HR rest	SBP rest	DBP rest
mean (NRF)	26.9±10.2	175.6±8.4	71.4±11.1	23.0±2.4	68.3±12.4	106.5±8.3	62.8±15.4
mean (RF)	*49.4±5.5	173.3±8.3	*80.8±18.0	*26.8±5.4	63.8±11.2	*118.4±16.0	*75.1±8.9

BMI – body mass index; HR rest – resting heart rate; SBP rest – resting systolic blood pressure; DBP rest – resting diastolic blood pressure

Figure 1.

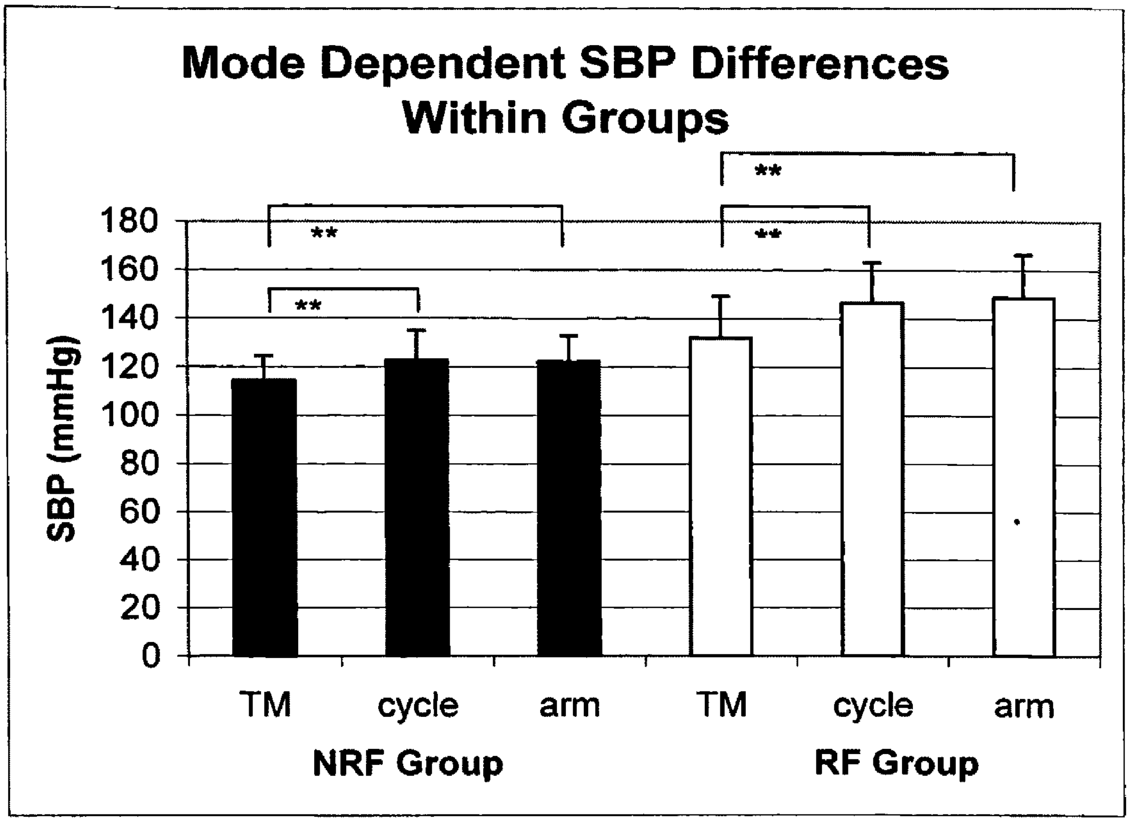
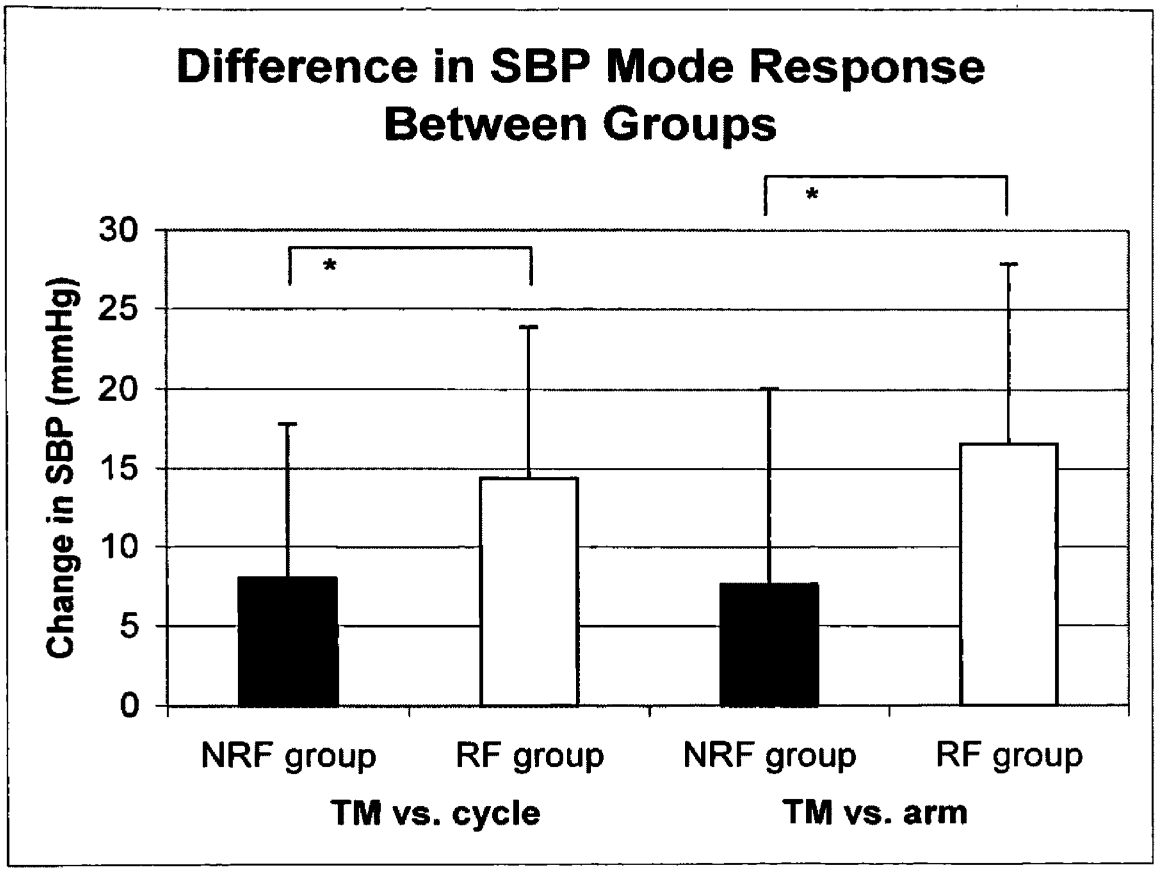

Mode Dependent SBP Differences
Within Groups
SBP (mmHg)
180
160
140
120
100
80
60
40
20
0
**
**
**
**
**
TM
cycle
arm
TM
cycle
arm
NRF Group
RF Group

Figure 2.


Difference in SBP Mode Response
Between Groups
Change in SBP (mmHg)
30
25
20
15
10
5
0
*
*
NRF group
RF group
NRF group
RF group
TM vs. cycle
TM vs. arm

DISCUSSION

Results of this study indicate that SBP values, and therefore RPP, are increased during cycling and arm exercise compared to treadmill walking when HR values are similar across exercise modes. In addition, it seems that individuals with ≥ 2 CAD risk factors are subject to a relatively greater SBP reactivity (larger increase in SBP and therefore RPP) between treadmill vs. cycle and arm exercise compared to individuals free from risk factors.

The increased SBP values during cycle vs. treadmill exercise observed in our study are similar to those reported by Coplan et al.[9], Yamakado et al.[15], Klein et al.[16], Calvert et al.[17], and Wetherbee et al.[18]. However, the elevated SBP displayed by our subjects during arm compared to treadmill exercise are contrary to the previous findings of Coplan et al.[10] who reported the opposite occurrence in young, healthy subjects. Certain methodological differences between the studies may explain the discrepancy in results. Coplan et al.[10] required subjects to completely cease arm cranking for 30 seconds, while we required subjects to continue cranking with one arm (at a reduced resistance) during SBP measurement. We chose our arm exercise SBP measurement methodology based on information provided by Hollingsworth et al.[19] who reported that SBP measured immediately *after* arm exercise significantly underestimated actual SBP obtained *during* exercise. In addition, our subjects exercised at a relatively lower intensity compared to those in the study conducted by Coplan et al.[10].

The different SBP responses between treadmill, cycle, and arm exercise were likely affected by many factors. Previously, Franklin[20] suggested that the decreased mechanical efficiency often associated with arm ergometry could increase SBP compared to various types of leg exercise. In addition, Franklin[20] and Coplan et al.[9] have reported that arm and cycle exercise often result in decreased stroke volume (SV) compared to treadmill walking exercise. Results from our study indicate that increased afterload (due to increases in SBP) may contribute to these lower observed SV levels previously reported. Another possible explanation for the changes in SV associated with these exercise modes may be a decreased preload or end-diastolic volume (EDV). EDV is affected by venous return, which is likely lower during arm and cycle exercise at least partially due to a decrease in the "blood pumping action" of contracting skeletal muscle (due to the decrease in recruited muscle mass). The decreased amount of muscle mass utilized during arm and cycle exercise also decreases peripheral vasodilation, which potentially may contribute to an increase in TPR and therefore SBP. Lastly, Franklin[20] has suggested that non-exercising muscle during arm exercise may exert an exaggerated vasoconstrictive response further elevating SBP values.

Another factor which may have influenced SBP results, may have been the lack of cycle and arm exercise mode specific training within our study population. Between both groups, no subjects regularly engaged in arm ergometry and only one subject utilized cycling as their primary mode of exercise. Hence, unfamiliarity/lack of training with these particular modes may have contributed to the elevated SBP values we observed. Although not evaluated in our study, another suggested factor possibly contributing to

SBP differences during arm exercise may be a decrease in vagal stimulation[21], which would cause an increase in both HR and BP. Additionally, the isometric hand-grip associated with arm cranking may have influenced SBP values. Although subjects were asked to lightly hold the treadmill and cycle bar to control for this factor, it is likely that subjects maintained a tighter grip during arm exercise compared to cycling and walking due to the nature of arm cranking.

Many factors may have contributed to the increased SBP reactivity response observed in the RF group including the perceived intensity of work or differences in subject characteristics between groups. It is difficult to isolate whether the reactivity was due to the slightly higher perceived intensity used in the RF compared to the NRF group, and/or the differing subject characteristics including age, weight, BMI, resting SBP, and resting DBP values between groups. The RF group exercised at a relatively higher intensity (mean fixed HR = 115.3 ± 11.3) compared to the NRF group (mean fixed HR = 100.4 ± 18.5). It is therefore possible that a larger percentage of the RF group may have been exercising above their anaerobic threshold during arm and cycle exercise while maintaining a workload below this level during treadmill walking since threshold levels tend to differ between modes of exercise. Previous research[22,23] has shown that SBP, HR, and RPP tend to increase in a non-linear fashion at exercise intensities above the anaerobic threshold. The exaggerated increase in these variables are likely due to the elevated levels of circulating catecholamines and increased sympathetic nervous activity that are associated with exercise intensities above the anaerobic threshold. Interestingly, Spence et al.[22] have reported that hypertensive individuals tend to display greater plasma catecholamine levels at the onset of blood lactate accumulation compared to untrained normotensive individuals at the same level of lactate accumulation. Therefore, our results may have implications for hypertensive individuals who may elicit even further exaggerated increases in SBP than was observed in our RF group.

Recent investigations[16,24,25] have shown an increased occurrence of silent or non-symptomatic ischemia associated with resting and exercise hypertension. In particular, Go et al.[25] found that acute, large increases in exercise BP as well as elevated SBP levels at the onset of ischemia, tended to decrease anginal pain perception in CAD patients. Furthermore, Klein et al.[16] reported silent ischemia to be three times more prevalent during cycling compared to treadmill exercise. Data from our study suggest that because SBP values seem to be elevated during cycle and arm exercise at fixed HR values, individuals with angina who engage in these activities may be more likely to experience silent ischemia. Additionally, results from the current study demonstrate an elevated SBP response during cycling, possibly suggesting that this may be a mechanism responsible for the occurrence of the hypertension-related hypoalgesia as reported by Klein et al.[16].

Although our study population did not include any subjects with CAD, it is possible that this group would elicit similar, if not exaggerated exercise SBP responses to those in our study. Because our study demonstrated that individuals with ≥ 2 risk factors elicited exaggerated SBP responses compared to individuals free of risk, it is logical to consider the possibility that individuals with additional risk factors, or those with CAD may display a similar, if not further exaggerated response. It is therefore important to consider these results in lieu of the potential impact it may have on this group during exercise.

In order to prevent myocardial damage, it is critical for angina patients to avoid exercise intensities that exceed anginal threshold. Because data from our study suggest that SBP, and therefore stress placed on the heart, is elevated during cycle and arm activity, exertion levels prescribed as THR ranges from treadmill GXT data may be inappropriate for individuals who utilize cycle and arm exercise. Walking may be a safer, and therefore more effective form of exercise for angina patients compared to cycling and arm ergometry because it places the least amount of strain on the heart at a comparable sub-maximal HR.

The results of this study are not only important for individuals diagnosed with silent ischemia, but also those with painful/symptomatic angina. These individuals who engage in cycle and arm exercise may fail to recognize when anginal threshold has been exceeded due to a blunted symptomatic perception of angina pain resulting from an acute elevation in SBP. Both physician and patient need to be aware of the potential implications of engaging in activities that may stimulate this response.

Study results may also apply to individuals diagnosed with resting or exercise hypertension. Hypertensive individuals should be made aware that cycling and arm exercise may result in exaggerated exercise blood pressure levels. Absolute exercise SBP values may need to be monitored periodically to ensure the maintenance of safe levels.

In conclusion, results from our study indicate that cycle and arm ergometer exercise may place more stress on the heart at a similar HR compared to treadmill walking. Therefore, it may be wise for physicians and health professionals to lower prescribed THR's (derived from treadmill GXT data), or to utilize mode specific testing, for angina patients (especially individuals with silent ischemia) who regularly engage in cycle and arm exercise. In addition, patients with angina should be informed that these activities may place an increased workload on the heart and additional mode specific monitoring may be warranted. Additional mode specific SBP monitoring may also be useful for hypertensive individuals who may elicit elevated values during cycle and arm exercise compared to treadmill walking. Further research is warranted utilizing a population of hypertensive and angina patients. This will allow us to investigate the possible further exaggerated mode specific differences in exercise SBP values.

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