Reprinted from JOURNAL OF CARDIOPULMONARY REHABILITATION
Vol. 8, No. 7, July 20, 1988


# Rate Pressure Product at Equivalent Oxygen Consumption on Four Different Exercise Modalities

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*Exercise prescription is frequently based on the premise that an equivalent oxygen consumption achieved on different exercise modalities will result in a similar cardiovascular response. To test this, a comparison was made of the rate pressure product occurring at an equivalent systemic oxygen consumption ($\dot{V}O_2$) while exercising on different modalities. Subjects ($n = 20$) performed maximal exercise tests at random over a 2-week period on nonconsecutive days on a treadmill, bicycle, rowing, and arm ergometers with an intermittent/incremental protocol and continuous ventilatory measurements. The heart rate and systolic blood pressure at equivalent $\dot{V}O_2$ on each exercise modality for each subject was determined from highly significant regression formulas based on the measures made during the tests. Rate pressure product was significantly higher ($P < .01$) during arm ergometry compared with other modalities at all intensities. Bicycle exercise resulted in a higher rate pressure product than treadmill exercise at high $\dot{V}O_2$ ($P < .01$), but did not differ significantly at lower intensities. Rowing elicited a lower rate pressure product at low $\dot{V}O_2$ ($P < .01$), but did not differ significantly from treadmill exercise at higher intensities. The results were gender independent. Different exercise modalities may result in a significantly different rate pressure product at an equivalent $\dot{V}O_2$. This should be considered when formulating an exercise prescription.*

## INTRODUCTION

The major determinants of myocardial oxygen demand are heart rate, ventricular wall tension, and contractile state of the heart.[1] Rate pressure product (RPP), the product of heart rate times systolic blood pressure (SBP), is a correlate of myocardial oxygen demand.[2–4] RPP has proven clinically useful since patients with obstructive coronary artery disease generally show evidence of myocardial ischemia during exercise at a reproducible RPP.[5–7]

Exercise prescription is frequently based on a target oxygen consumption ($\dot{V}O_2$), or MET level (1 MET = 3.5 ml $O_2 \cdot kg^{-1} \cdot min$), from treadmill testing. However, the relationship of heart rate and systolic blood pressure to $\dot{V}O_2$ is not the same for purely static versus dynamic exercise,[8,9] resulting in a greater RPP for a given $\dot{V}O_2$ during static exercise. In addition, the relationship of RPP to $\dot{V}O_2$ is not the same for purely upper body versus lower body exercise.[10–13] To evaluate this further, we studied the relationship of RPP at equivalent levels of $\dot{V}O_2$ during treadmill testing and other exercise modalities that are currently used for aerobic training.

## METHODS

Ten healthy men and ten healthy women served as subjects. The mean age was 29 ± 1 years (mean ±

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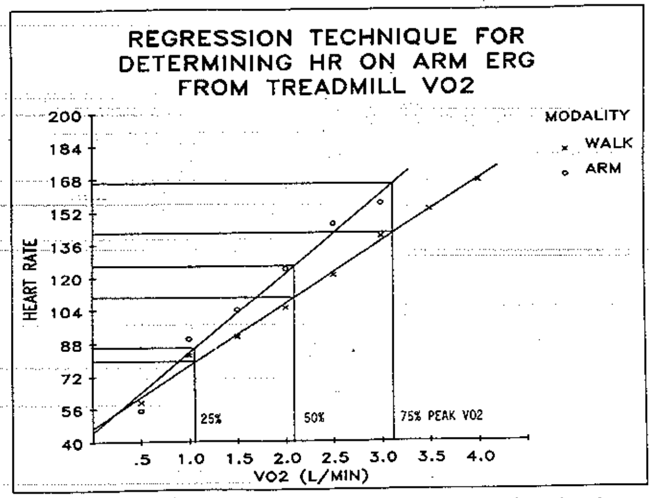


**Figure 1.** Regression technique for comparing heart rate on different modalities at the same oxygen consumption. This procedure was also used for comparing SBP and RPP from different exercise modalities at equivalent oxygen consumptions. HR = heart rate; $\dot{V}O_2$ = oxygen consumption.

SEM). All subjects were normotensive and were taking no medications. There was no selection criteria relative to training status; 12 of 20 subjects incorporated some form of exercise into their daily routine 3 or more days/week.

All subjects exercised at random on four exercise modalities: (1) motorized treadmill, (2) bicycle ergometer, (3) rowing ergometer, and (4) arm ergometer. Each test was separated by at least 2 days, and the four tests were completed within a 2-week period. Subjects who had never used a rowing ergometer were given time to familiarize themselves with the apparatus on a separate day.

Subjects performed incremental exercise to volitional fatigue. The exercise protocols were devised to keep the experience on each modality as similar as possible. Exercise on bicycle, arm, and rowing ergometer was done at constant cycle rate and progressively increasing resistance; each stage of work was 3 minutes long, followed by a 30-second rest period for the attainment of blood pressure by auscultation. Starting work rates on the bicycle were 400 KPM, increasing by 200 KPM for men and 150 KPM for women with each stage. The arm ergometer began with a work rate of 25 watts and increased by 20 watts for men and 15 watts for women. The rowing ergometer began at 7 to 8 Calories/minute and increased by 2 Calories/minute at each stage for men. The corresponding values for women were 6 to 7 Calories, increasing by 1 to 2 Calories/min. (Calorie here is referred to as the unit of work indicated by the ergometer. It is an overestimation, based on oxygen consumption measures.) The treadmill protocol also involved 3-minute stages beginning with a speed of 3.5 mph and increasing by 5% grade at each stage until 25% grade was reached. Thereafter, speed was increased by 1 mph each stage. In all cases, BP was obtained during a 30-second rest after each stage. Heart rate and oxygen consumption were taken from the last minute of each stage of work.

**TABLE I**
**PEAK VALUES ON FOUR EXERCISE MODALITIES***

| | Oxygen Consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) | Heart Rate (beats/min) | RPP × $10^2$ |
|---|---|---|---|
| Women | | | |
| Walk | 45.6 ± 2.1 | 184 ± 3 | 34.2 ± .9 |
| Bike | 44.1 ± 2.2 | 182 ± 3 | 34.9 ± .9 |
| Row | 42.1 ± 2.3 | 180 ± 5 | 31.3 ± 1.0 |
| Arm | 28.3 ± 2.2 | 166 ± 5 | 26.8 ± 1.1 |
| Men | | | |
| Walk | 54.5 ± 2.8 | 187 ± 3 | 40.4 ± 1.3 |
| Bike | 51.2 ± 2.5 | 182 ± 3 | 38.9 ± 1.4 |
| Row | 47.3 ± 2.5 | 177 ± 3 | 37.5 ± 1.8 |
| Arm | 37.0 ± 2.1 | 172 ± 3 | 32.9 ± 1.3 |

*All values are expressed as mean ± SEM.

$\dot{V}O_2$ was measured continuously by a SensorMedics Metabolic Measurement Cart (Sensor Medics Corp., Anaheim, CA). Calibration with standard gases spanning a range of 0–4% $CO_2$ and 0–16% $O_2$ was performed before each test. Heart rate (HR) was obtained from an electrocardiogram monitored continuously in leads II, AVF, and V5.

**Calculations.** To compare RPP, HR, and SBP at the same $\dot{V}O_2$, regression equations relating: (1) $\dot{V}O_2$ to RPP, (2) $\dot{V}O_2$ to HR, and (3) $\dot{V}O_2$ to SBP were developed for each patient, based on the data recorded from exercise on each modality. All regressions formed were highly significant with correlation coefficients in excess of .90 in all cases and frequently greater than .95. The HR, SBP, and RPP occurring at equivalent $\dot{V}O_2$ on each modality was then determined using the $\dot{V}O_2$ at 25%, 50%, and 75% of $\dot{V}O_2$ max on the treadmill. For example, a subject with $\dot{V}O_2$ of 40 $ml \cdot kg^{-1} \cdot min^{-1}$ on the treadmill would have a corresponding HR from each modality determined at 10, 20, and 30 $ml \cdot kg^{-1} \cdot min^{-1}$. Figure 1 shows use of regressions to determine HR at equivalent $\dot{V}O_2$ during arm exercise and treadmill exercise for one subject. (For this population, these percentages of $\dot{V}O_2$ max averaged 29%, 53%, and 73% maximum heart rate reserve).

Comparison of RPP, HR, and SBP among modalities was made by a repeat measures analysis of variance. When a significant F-ratio was found, *post*

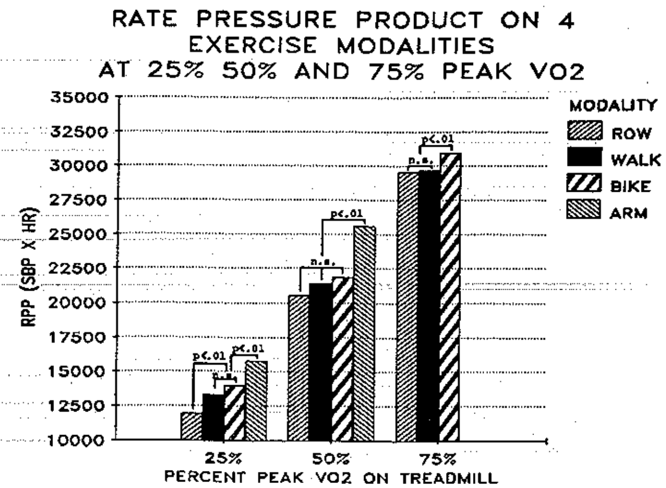


**Figure 2.** RPP at equivalent $\dot{V}O_2$ on each modality. Peak treadmill $\dot{V}O_2$ was used as the standard for determining sampling points; RPP was determined at the equivalent of 25%, 50%, and 75% of peak treadmill $\dot{V}O_2$. Probability values are listed over the bars (n.s. = no significant difference). Arm values at 75% $\dot{V}O_2$ are omitted because only eight subjects attained a $\dot{V}O_2$ of 75% peak treadmill values with arm ergometry. HR = heart rate; RPP = rate pressure product; $\dot{V}O_2$ = oxygen consumption.

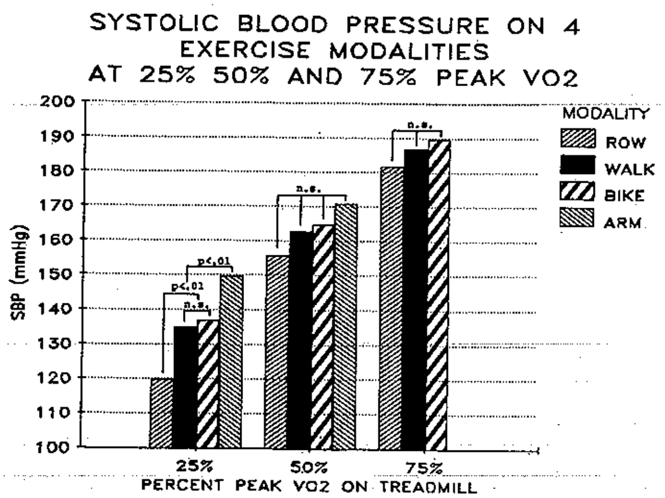


**Figure 3.** SBP at 24%, 50%, and 75% of peak treadmill $\dot{V}O_2$ for each modality. Arm values at 75% are omitted because only eight subjects attained a $\dot{V}O_2$ of 75% peak treadmill values with arm ergometry.

*hoc* testing was done to determine which modalities differed from others.[14]

## RESULTS

Subjects were in good to high aerobic condition by American Heart Association standards[15]; men averaged a peak $\dot{V}O_2$ of $54.5 \pm 2.8$ ml · kg$^{-1}$ · min$^{-1}$, and women $45.6 \pm 2.1$ ml · kg$^{-1}$ · min$^{-1}$. The walking protocol resulted in the highest peak values

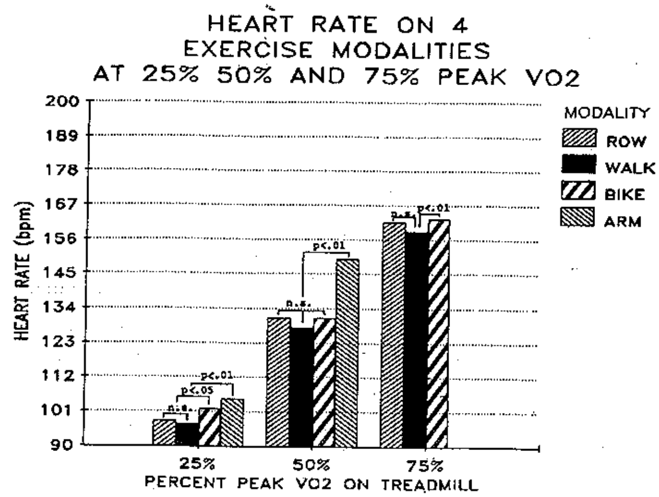


**Figure 4.** HR at 25%, 50%, and 75% of peak $\dot{V}O_2$ on the treadmill for each modality. Arm values at 75% are omitted because only eight subjects attained a $\dot{V}O_2$ of 75% peak treadmill values with arm ergometry.

($P < .01$) of any of the modalities for both genders (Table I). Men attained higher peak $\dot{V}O_2$ values on all modalities compared with women ($P < .01$).

The RPP for each modality at 25%, 50%, and 75% of peak $\dot{V}O_2$ on the treadmill is shown in Figure 2. There was no significant interaction of gender with modality; therefore, men and women have been combined. At a $\dot{V}O_2$ of 25% peak on the treadmill, rowing produced a significantly lower ($P < .01$) RPP than walking, biking, and arm ergometry. This represents about 29% of maximum heart rate reserve. Arm ergometry produced a higher RPP ($P < .01$) than all modalities. At a $\dot{V}O_2$ equivalent to 50% of treadmill peak (about 53% maximum heart rate reserve), RPP during arm ergometry was significantly higher ($P < .01$) than all modalities as well. There was no significant difference among the other modalities at this $\dot{V}O_2$.

Only eight subjects attained a $\dot{V}O_2$ equivalent to 75% of peak treadmill values (or about 73% maximum heart rate reserve) during arm ergometry. RPP was significantly higher during arm ergometry ($32740 \pm 1471$, $P < .01$) than on the other modalities in these subjects. Using data from all 20 subjects, the RPP at a $\dot{V}O_2$ of 75% peak on the treadmill was significantly greater for bicycling ($P < .01$) than for rowing and treadmill exercise (which did not differ from one another).

SBP is higher for arm ergometry only at a $\dot{V}O_2$ equivalent to 25% peak on the treadmill ($P < .01$, Fig. 3). Rowing produced a significantly lower SBP ($P < .01$) than any of the other modalities at this energy expenditure. No other significant differences existed for SBP with increased work intensity.

HR (Fig. 4) was significantly higher at a $\dot{V}O_2$ of 25% peak on the treadmill for both bicycling ($P < .05$) and arm ergometry ($P < .01$), which did not differ from each other. HR was significantly higher at 50% for arm ergometry only ($P < .01$). In eight subjects who attained 75% of peak treadmill $\dot{V}O_2$ during arm ergometry, HR was significantly higher ($176 \pm 4$, $P < .01$) than on the other modalities. HR was significantly higher for cycling ($P < .05$) than for either walking or rowing at 75% of peak $\dot{V}O_2$ (73% maximum HR reserve) on the treadmill.

## DISCUSSION

An exercise prescription is frequently based on the results of treadmill exercise. The recommendations are then generalized to other forms of exercise, using MET levels (or a percentage of maximum HR reserve) as a means for deriving equivalent exercise intensity. However, the results of this study indicate that equivalent exercise (based on oxygen consumption) on different exercise modalities may result in significantly different RPP. RPP, a clinical correlate of myocardial oxygen demand, was found to be higher for the same whole body $\dot{V}O_2$ during either arm (at all intensities) or leg cycle ergometry (at 75% peak $\dot{V}O_2$, or 73% maximum HR reserve) than during treadmill exercise. Rowing ergometry elicited a lower RPP at 25% and did not differ significantly from treadmill exercise at the higher intensities examined. These findings were not influenced by gender.

**Upper vs. Lower Body Exercise.** Upper body cycling is less mechanically efficient than lower body cycling, so that more oxygen is used for a given amount of external work.[16] Furthermore, the speed of upper body cranking has a significant effect on the mechanical efficiency of movement.[17] More importantly, the RPP is known to be higher in upper body ergometry than lower body ergometry at the same $\dot{V}O_2$,[16] a fact that should be considered when prescribing exercise with the upper body.[18]

Many explanations for the increased RPP during upper body ergometry have been advanced. There is less decline in total peripheral resistance during upper body work than lower body work,[12,19] perhaps due to the amount of actively exercising muscle. In addition, an increased component of static work due to gripping the handles in upper body exercise is not present in lower body exercise. Adding static work to dynamic work has been shown to increase the HR and SBP response to dynamic exercise.[4] Sympathetic activity may be higher for a specific MET level in upper body exercise due to the increased static component of gripping. Another consideration is that reduced ventricular filling pressure during upper body work may necessitate increased sympathetic nervous system activity to maintain required cardiac output through an augmented HR response.[20]

The degree of training also may result in differences between the upper and lower body.[21] The relationship between $\dot{V}O_2$ and RPP is influenced by training, and the effect is specific for the muscle groups trained.[22] Lower body muscles are used more frequently and therefore may manifest a lower RPP than the upper body at an equivalent $\dot{V}O_2$.

**Combined Upper and Lower Body Exercise.** Combined cycling exercise with the upper and lower body can produce a higher $\dot{V}O_2$ max than either body segment alone.[23,24] A larger actively exercising skeletal muscle mass may explain this finding. Submaximal exercise does not show an increased HR response to combined upper and lower body exercise if at least 40% of the total work is performed with the lower body.[20]

Rowing, the form of combined upper and lower body exercise used in this study, is not totally analogous to simultaneous upper and lower body cranking. More emphasis is placed on use of the trunk musculature during rowing and less on the arms. Nevertheless, our results indicate that for a given energy expenditure, rowing elicits a comparable or lower RPP than walking on the treadmill.

**Cycling vs. Walking.** Maximal HR and $\dot{V}O_2$ are known to be lower for cycling than for running.[25] Davis et al. showed that $\dot{V}O_2$ at the anaerobic threshold did not differ between cycling and running in college-age males[26]; however, no HR and SBP data were shown. Our results indicate that RPP can be expected to be higher on the bike than on the treadmill at a $\dot{V}O_2$ equivalent to 75% peak on the treadmill. A possible explanation for this finding is that muscles used in cycling may not have the same degree of training as those used in walking and running in the population studied. As already noted, the degree of training of skeletal muscle can affect the cardiovascular response to exercise.[22]

**Limitations.** Although an equivalent $\dot{V}O_2$ on the four modalities tested does not yield the same RPP, myocardial oxygen demand does not necessarily differ at equivalent systemic $\dot{V}O_2$ across modalities. It was originally shown that anginal threshold occurred at a comparable RPP for upper and lower body ergometry[7]; however, later work found that the anginal threshold occurred at a higher RPP for the upper body.[27,28] Because RPP does not directly account for changes in end diastolic volume, a determinant of myocardial oxygen demand,[1] dissimilar end diastolic volumes have been postulated as an explanation. Stroke volume has been shown to be less during arm work, presumably due to a decreased end diastolic volume.[22] However, determination of left ventricular wall stress with echocardiography in normals was unable to show a difference at a comparable peak RPP between upper body and lower body cranking.[29]

Posture may also have a significant effect on the relationship of RPP to myocardial oxygen demand. Supine leg cycling has been shown to result in no increase in stroke volume with increasing work intensities, which produced increased stroke volume in upright cycling.[30] Therefore, postural effects may have a significant influence on our findings. Rowing is the only form of recumbant exercise used in this study. Myocardial oxygen demand may be different compared with the same RPP in upright exercise.

The subjects in this study were not taking any medications. Patients receiving medications that affect cardiovascular dynamics (*e.g.* beta blockers, nitrates, calcium channel blockets) may have a different response to exercise on different modalities than our subjects, and are an important area for further investigation.

**Clinical Implications.** This study compared the heart rate and hemodynamic response with exercise on different modalities at equivalent oxygen consumption. Using oxygen consumption as a means to generalize optimal exercise intensity from treadmill testing to other exercise modalities is based on the principle that different types of exercise that elicit the same $\dot{V}O_2$ will result in a similar cardiovascular response and myocardial oxygen consumption. This implies that equivalent work has an equivalent cardiovascular effect, regardless of how it is achieved. Our results show that this is not necessarily true, raising questions about the efficacy of using METs (or a percentage of maximum HR reserve) for exercise prescription across exercise modalities. Differences in the myocardial response when attaining the same oxygen consumption on different modalities may result in a myocardial oxygen demand that varies from what would be expected based on observations during treadmill testing, and should be considered when advising patients regarding exercise.

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