Biology of Sport, Vol. 20 N°1, 2003

THE RATE PRESSURE PRODUCT IS GREATER DURING SUPINE CYCLE ERGOMETRY THAN DURING TREADMILL RUNNING

S.R.Simonson[1], F.B.Wyatt[2]

[1]Western New Mexico University, Dept. of Wellness and Movement Sciences, Silver City, New Mexico, USA; [2]Baylor University, Dept. of Health, Human Performance, and Recreation, Waco, Texas USA

Abstract. Supine cycle ergometry (SCE) is used to assess cardiopulmonary fitness and reserves and to predict potential cardiopulmonary complications of cardiac patients and those undergoing abdominal and non-cardiac thoracic surgery. It is also used to simulate exercise during spaceflight. The question arises as to how SCE compares to upright treadmill running (TMR). The purposes were: 1) to compare oxygen uptake, heart rate, blood pressure, and work of the heart (rate-pressure product, RPP) obtained during maximal bouts of SCE and TMR exercise; 2) to compare these parameters at similar oxygen uptakes during SCE and TMR; and 3) to establish a formula for predicting TMR performance based on SCE. Nine males, ages 21-35 years ($\bar{x}$ =27.44 yr) completed the Bruce TMR and a ramped SCE protocol to determine device specific peak oxygen uptake. Respiratory gasses and volumes, heart rate, blood pressure, and rating of perceived exertion were measured. Oxygen uptake, RPP, mean arterial pressure, parameter means and standard errors were calculated and a paired *t*-test ($P \leq 0.05$) performed. Absolute and relative peak oxygen uptake and peak heart rates were greater for TMR. SCE produced higher values for systolic, diastolic, and mean arterial pressures, and RPP. Although TMR produces greater systemic stress, SCE causes the greatest exertion by the heart. RPP should be used for evaluation and prescription of exercise rather than HR or BP alone. Increased wall motion abnormalities and ischemic events noted during supine exercise may be due to the heart working harder as well as to better imaging capabilities.

(Biol.Sport 20:3-14, 2003)

Key words: Oxygen uptake - Rate pressure product - Supine ergometry

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Reprint request to: Shawn R. Simonson, Ed.D., Dept. of Wellness and Movement Sciences, Western New Mexico University, P.O. Box 680, Silver City, New Mexico USA 88062, Tel.: (505) 538-6469, Fax: (505) 538-6209, E-mail: simonsons@wnmu.edu

Introduction

Exercise stress testing is a valuable tool for assessing the potential for and severity of coronary artery disease [18,27]. It is also used to determine maximum cardiac and aerobic capabilities for exercise prescription, determination of the effects of conditioning, and the measurement of deconditioning [21,22]. A maximal stress test provides information concerning the functional capabilities of the cardiovascular and pulmonary systems [18,27].

The treadmill is often considered the best apparatus for providing maximal stress and for determining maximal oxygen uptake [22]. It is preferred for two major reasons: 1) people are familiar with walking and running, and 2) this activity involves the largest muscle groups of the body [7]. Peak oxygen uptake values obtained on the treadmill are usually equal to, or greater than all other protocols for measuring oxygen uptake [4].

Supine cycle ergometry (SCE) is used for assessment of cardiopulmonary fitness for cardiac patients, especially those preparing to be discharged from hospital cardiac care [26]. It is also used to identify cardiac regional wall motion abnormalities via echocardiography during exercise [6,15]. SCE provides more accurate echocardiography detection of myocardial ischemia during exercise than post-treadmill exercise echocardiography [5]. SCE is performed prior to abdominal and non-cardiac thoracic surgery to determine cardiopulmonary reserve, and then predict potential pulmonary and cardiac complications (the major causes of morbidity during these surgeries) [17]. The supine position is also utilized to simulate the headward fluid shifts seen during space flight [20]. A headward shift of fluid increases the venous return and the ejection fraction and, therefore, the stroke volume [24]. This increased workload may be contrary to the intentions of the cardiologists and responsible for the increased abnormalities noted in this position. The purpose of this study was threefold: 1) to compare the heart rate, blood pressure, mean arterial pressure, and work of the heart at peak and during workloads at similar oxygen uptakes on the supine cycle ergometer and the upright treadmill, 2) to determine which mode causes the heart the greatest stress, and 3) to establish a formula for predicting treadmill running (TMR) performance based on SCE.

Material and Methods

Nine men (27±4 yr., 181.97±5.18 cm, 81.87±8.69 kg) volunteered from the university community. All were routinely active at a level above that suggested by the American College of Sports Medicine for maintenance of health and fitness [25].

They provided informed consent and completed a health history questionnaire to determine fitness for participation [2,11]. A healthy population was used rather than a cardiac patient population to allow for asymptomatic maximal work and to reduce the potentially confounding variable of cardiac distress.

Subjects avoided food for 6 h, caffeine for 12 h, and exercise for 24 h prior to exercise. They consumed 0.5 L of water the night before and the morning of the test to insure euhydration. There was one week between maximal exercise bouts. The order of the tests was randomized.

Resting heart rate (bpm), blood pressure (mmHg), and oxygen uptake (L/min, $ml \cdot kg^{-1} \cdot min^{-1}$) were measured after 10 min of seated rest before TMR and 30 min of supine rest before SCE.

The Bruce protocol was used to determine peak oxygen uptake on the upright treadmill. A ramped peak ergometer protocol was used to determine peak oxygen uptake on the supine cycle ergometer. This was continuous with the initial workload at 100 W for 4 min with subsequent 20 W increases in resistance every 4 min (Table 1). Heart rate was monitored via Polar heart rate monitor (Polar Vantage, Polar Electronics, Port Washington, NY). Blood pressure was measured via auscultation of the brachial artery [1] by an ACSM certified Exercise Test Technologist. Respiratory gasses and volume were measured with Ametek gas analyzers (models S3-A and CD-3A, Applied Electrochemistry, Pittsburgh, PA). A ventilation measurement was taken each 2 min during submaximal effort and at the end of each minute as maximal effort was approached. A subjective rating of perceived exertion was obtained using the modified Borg scale (1-10) [10]. The test was terminated at volitional fatigue.

Table 1
Stages of the ramped peak supine ergometer test

Stage	Time (min)	Speed (rpm)	Resistance (W)
1	4	70	100
2	4	70	120
3	4	70	140
4	4	70	160
5	4	70	180
6	4	70	200

Table 2
Results of the assessment of maximal oxygen uptake, heart rate, and blood pressure for supine and treadmill maximum stress tests

Time (min)	VOL (L/min)	$\dot{V}O_2$ (L/min)	$\dot{V}O_2$ (mL/kg-min)	HR (bpm)	BP (mmHg)	MAP (mmHg)	RPP	RPE (1-10)
Supine								
15.11*	131.10	4.11*	50.55*	175*	197*/87*	142*	344.7*	10
±1.03	±8.29	±0.33	±4.61	±5.07	±3/3	±2	±12.9	±0
Treadmill								
10.22	148.88	5.23	64.54	187	170/77	124	319.3	10
±0.43	±7.57	±0.16	±3.41	±2.80	±3/2	±1	±8.7	±0.1

Key to Tables 2 and 3 abbreviations:
Time is the time until volitional fatigue and cessation of the maximal bout; VOL is the volume of gas inspired in liters at STPD; $\dot{V}O_2$ (L) is the absolute maximal oxygen consumption expressed in liters; $\dot{V}O_2$ (mL/kg-min) is the relative maximal oxygen consumption corrected for the mass of the subjects; HR is the heart rate obtained at the time of maximal oxygen consumption; BP is the blood pressure measured in mmHg and noted as systolic/diastolic; MAP is the mean arterial pressure in mmHg as determined by (systolic - diastolic)/3 + diastolic; RPP is the rate pressure product as determined by (systolic x heart rate)/100; RPE is rating of perceived exertion using the modified Borg Scale [10]

Oxygen uptake was calculated using $\dot{V}O_2 = \dot{V}O_{2inspired} - \dot{V}O_{2expired}$. Peak oxygen uptake was the highest oxygen uptake obtained, an RPE of 10, and volitional fatigue. Mean arterial pressure was MAP = [(systolic blood pressure-diastolic blood pressure)/2] + diastolic blood pressure. RPP = (systolic blood pressure x heart rate)/100. Similar oxygen uptakes were identified across apparati and compared by pairing mode specific values for each subject. Oxygen uptake values selected were within ±0.1 $mL \cdot kg^{-1} \cdot min^{-1}$.

Means, standard errors (SE), and standard deviations (SD) were calculated for all data sets and *t*-tests with paired observations performed to compare the means [19]. Statistical significance was determined with α set at $P \leq 0.05$. A Pearson Product R correlation coefficient was utilized to determine associate between variables. A post hoc regression analysis was run utilizing variables found to be significantly correlated.

Results

A greater peak oxygen uptake and heart rate were achieved with TMR (64.5±3.4 $mL \cdot kg^{-1} \cdot min^{-1}$, 187±3 bpm) as compared to SCE (50.6±4.6 $mL \cdot kg^{-1} \cdot min^{-1}$, 175±5 bpm, (Table 2). At the lower peak oxygen uptake obtained during SCE, the volume of air inspired was equal to that measured at peak TMR. The greatest systolic, diastolic and mean arterial pressures were attained with SCE. This resulted in SCE having a significantly greater RPP than TMR (Fig. 1). The rating of perceived exertion was equal.

Table 3
Comparison of cardiovascular parameters for the supine ergometer and treadmill when oxygen consumption is equal

VOL (L/min)	$\dot{V}O_2$ (mL/kg-min)	HR (bpm)	BP (mmHg)	MAP (mmHg)	RPP	RPE (1-10)
Supine						
66.64*	33.70	151	178*/85*	132*	271.9*	5*
±2.15	±0.30	±6	±4/3	±2	±15.2	±0
Treadmill						
59.91	34.18	151	149/73	111	226.0	4
±2.41	±0.65	±3	±2/2	±1	±6.4	±0

$\bar{x}$ ±SE; *Significant difference at the P≤0.05 level

When data for similar oxygen uptakes were compared between treatments, heart rate was also similar (Table 3). At similar oxygen uptakes, the volume of air inspired during SCE (66.6±2.1 L/min) was higher than TMR (59.9±2.4 L/min). Again, systolic, diastolic and mean arterial pressures were greater for SCE than for TMR. The SCE RPP (271.9±15.2) was still significantly elevated above that of TMR (226.0±6.4) at similar oxygen uptakes as was the rating of perceived exertion (Fig. 2). The SCE rating of perceived exertion was greater than that of TMR.

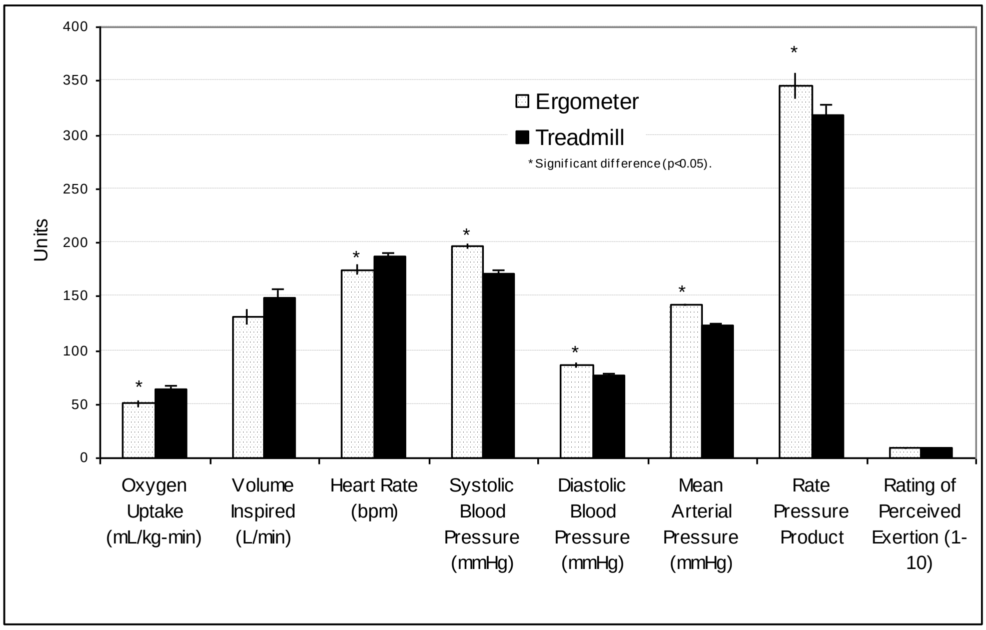

Fig. 1

Mean (±SD) peak values for the ergometer (supine) versus the treadmill (upright) during maximum stress tests

The regression equation for predicting TMR $\dot{V}O_2$max from SCE $\dot{V}O_2$peak is TMR $\dot{V}O_2$max=0.53·SCE $\dot{V}O_2$peak+37.64, r=0.72 (Fig. 3). The regression equation for predicting TMR RPP from SCE RPP is $TMR_{RPP}=0.83SCE_{RPP}+24.31$, r=0.77 (Fig. 4). Data points represent the pairing of similar SCE and TMR $\dot{V}O_2$, thus a greater number of data points than the total n were used as multiple pairings were possible.

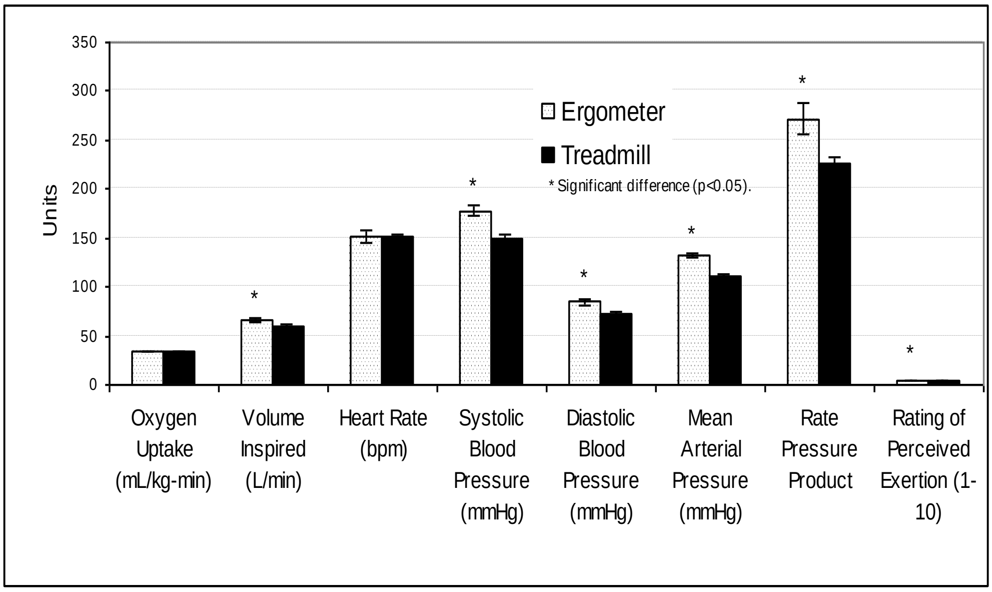

Fig. 2
Mean (±SE) responses for the ergometer (supine) versus the treadmill (upright) at similar oxygen uptake

Discussion

The headward fluid shift caused by exercise in the supine position increases the venous return and the ejection fraction and, therefore, the stroke volume [24]. This increased workload may lead to the increased incidence of cardiac abnormalities noted during SCE. The purposes of this study ware to compare the heart rate, blood pressure, mean arterial pressure, and work of the heart at peak and during workloads at similar oxygen uptakes on the supine cycle ergometer and the upright treadmill, to determine which mode causes the heart the greatest stress, and to establish a formula for predicting TMR performance based on SCE.

As expected, the peak oxygen uptake was greater on the treadmill than it was on the supine ergometer. The findings of this study of SCE at 78% of TMR falls within the range of 77–85% noted by others [3,13,26]. The mechanisms for this lower peak oxygen uptake are discussed elsewhere [29].

Blood pressure increased more with the supine exercise than with the treadmill. This is due to the increased venous return due to the body position [24,28]. Increased venous return leads to a greater end diastolic volume and therefore a greater ejection volume via the Frank-Starling mechanism. This greater ejection volume leads to a greater systolic blood pressure [16]. A greater systolic blood pressure is necessary to help pump the blood up to the legs rather than the gravity assisted pumping to the working muscles during treadmill running. Also, the increased diastolic pressure is not unusual for the supine position. Due to the horizontal position of the body, fluids shift from the storage veins of the legs to the upper body [12,20]. This leads to a greater fluid volume in the upper body, which results in greater cardiac output and venous pressure [8]. Increased fluid levels do not allow for as much relaxation of the vessel walls, leading to a greater resting diastolic pressure.

The increased systolic and diastolic blood pressures resulted in a greater mean arterial pressure for the supine exercise. Increased mean arterial pressure causes a greater driving force to push fluids out of the blood vessels, into the tissues, and eventually out of the body via sweat and urine [16].

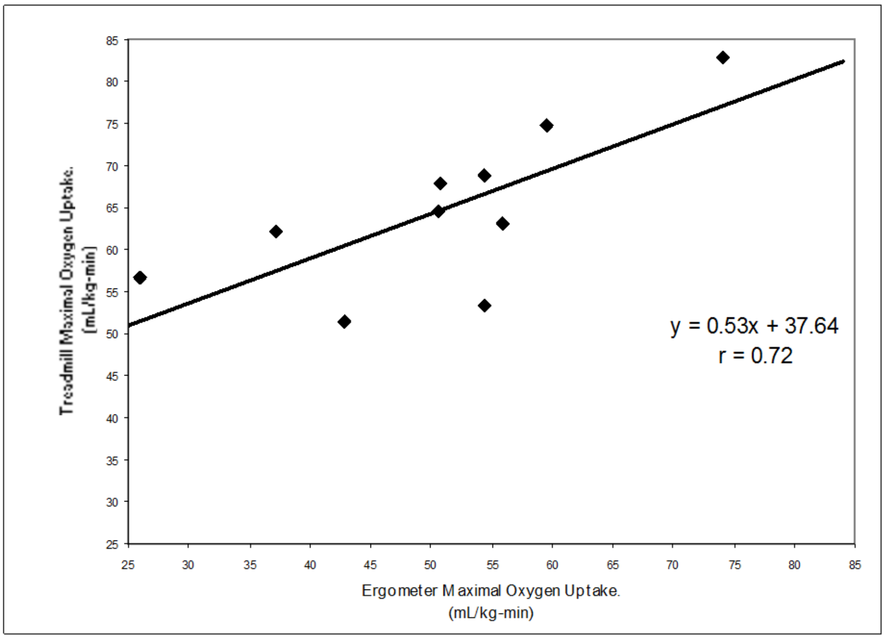

Fig. 3
Regression equation for prediction of treadmill maximum oxygen consumption from supine cycle ergometry

The greater cardiac output leads to a greater myocardial oxygen demand (calculated non-invasively as the rate pressure product) [23]. Thus the SCE RPP is elevated above TMR at both maximal effort and at similar total oxygen uptakes. Even though systemic energy expenditure is greater during maximal TMR, the heart has a greater oxygen consumption and work output during maximal SCE.

The regression equation for predicting TMR $\dot{V}O_2max$ from SCE $\dot{V}O_2peak$ is TMR $\dot{V}O_2max$=0.53·SCE $\dot{V}O_2peak$+37.64, r=0.72 (Fig. 3). The regression equation for predicting TMR RPP from SCE RPP is TMR_{RPP}=0.83SCE_{RPP}+24.31, r=0.77 (Fig. 4).

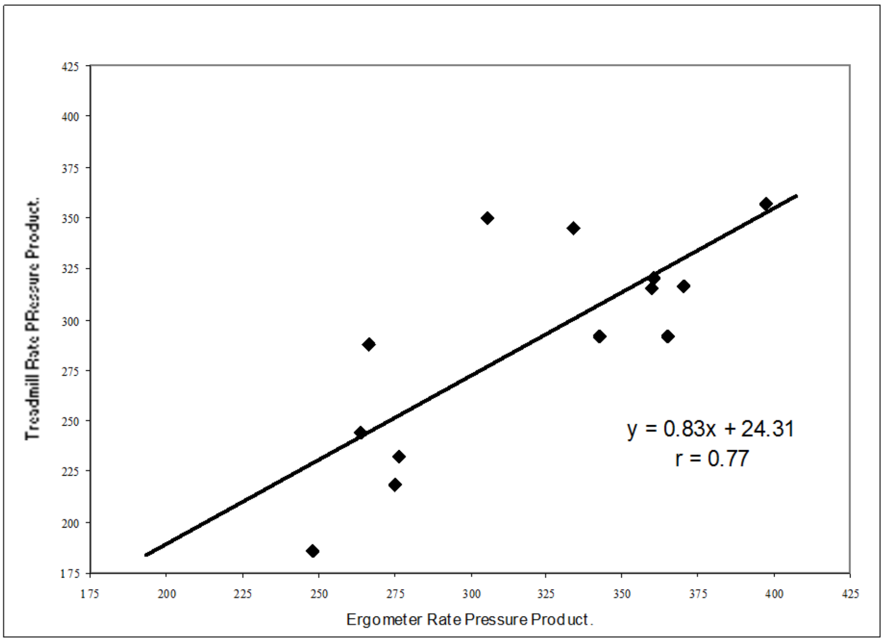

Fig. 4
Regression equation for prediction of treadmill rate pressure product from supine cycle ergometry

When oxygen uptakes of similar values are compared, the volume of air inspired, blood pressure, mean arterial pressure, and RPP are elevated for supine ergometry as compared to treadmill running. This indicates that the heart is working harder during supine ergometry to create the same systemic utilization of oxygen. This is in agreement with previous work that found the RPP and cardiac output to be higher during supine exercise than upright for a given submaximal oxygen uptake [9,14]. The RPP is indicative of myocardial oxygen uptake and is strongly correlated to ischemia and the associated angina and ST segment depression [2,23]. The results of this study indicate that when headward fluid shifts occur, resulting in a greater fluid volume in the thoracic region [20,24], heart rate and oxygen uptake are no longer accurate measures of cardiac stress. As the RPP is an estimate of myocardial oxygen demand [23], it may be a more accurate indicator of ischemic event onset and wall motion abnormalities than heart rate and/or oxygen uptake. Therefore, the RPP should be used for evaluation and prescription of exercise rather than HR or BP alone. Additionally, the increased number of wall motion abnormalities [6,15] and ischemic events [6,27] noted during supine exercise may be due to the heart working harder as well as to better imaging capabilities. Thus, although TMR places the greatest systemic stress on the individual, SCE causes the greatest exertion by the heart.

Based on the results of this study, caution must be used before allowing individuals with the potential for pulmonary or cardiac difficulty to participate in supine exercise. With the increased work of the heart during supine ergometry, as compared to the upright treadmill, care must be taken when using supine ergometry to prescribe treadmill exercise (or vice versa). As evidenced from this research, the load on the heart during these two modes is not equivalent.

In addition, exertion during space flight may also be erroneously monitored in that the redistribution of body fluids may be causing the heart to work harder than oxygen uptake or heart rate might indicate when compared to activity in eugravity.

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Accepted for publication 31.01.2002

Acknowledgements

·The research was completed at the University of Northern Colorado, Greeley, Colorado 80639.

The authors wish to thank Dr. John Greenleaf and Ms. Stephenie Cowell for editorial assistance and the test subjects for their enthusiastic participation.