ORIGINAL RESEARCH ARTICLE

Cardiopulmonary responses to kayak ergometer and treadmill exercise in canoeists

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Abstract

Objective. To determine if the cardiorespiratory response of canoeists is the same for upper and lower-limb exercise so that guidelines might be established for the use of heart rate monitoring for canoe training.

Design. Prospective, randomised, crossover study.

Setting. A tertiary education exercise laboratory.

Interventions. Thirteen canoeists were randomly assigned to perform an incremental maximal oxygen consumption test (VO_{2max}) to exhaustion on a treadmill and on a kayak ergometer with a 5 – 7-day break between tests.

Main outcome measures. Computerised open circuit spirometry was used to determine oxygen consumption, carbon dioxide production, tidal volume, respiratory rate, metabolic equivalents, oxygen and carbon dioxide equivalents, respiratory exchange ratio and oxygen pulse. Heart rate was monitored using telemetry.

Results. Maximum heart rate on the kayak ergometer was 97% of that on the treadmill, and kayak ergometer VO_{2max} was 80% of treadmill VO_{2max}. During upper-limb submaximal exercise, heart rates were significantly higher with respect to oxygen consumption ($p < 0.0001$), as was the respiratory rate ($p < 0.0001$), while the tidal volume was decreased ($p < 0.0001$). Minute volume was higher on the kayak ergometer for all but the highest exercise intensities. The relationship of the percentage maximum heart rate to percentage VO_{2max} was similar for upper and lower-limb exercise. Use of leg-derived HR_{max} to set training intensities for canoeing would result in the paddler training at a $\%VO_{2max}$ that was 7.2% higher at 60% leg HR_{max}, 5.7% at 70% leg HR_{max}, 4.3% at 80% leg HR_{max}, and 2.8% at 90% leg HR_{max}.

Conclusions. As the kayak HR_{max} in this study is 97% of the treadmill HR_{max}, training zones for canoeing based on leg HR_{max} will in general be suitable, with the proviso that a minority of canoeists may have markedly lower upper-limb VO_{2max}.

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Introduction

Canoeing, or kayaking as it is known internationally, is a growing sport that has received relatively little attention from sports scientists. Marathon and ultra-distance marathon canoeing are the most popular canoeing disciplines in South Africa, with race distances varying from 20 km single-day events, to 200 km multi-day events. In many major races the competitors must carry or portage their canoes around dangerous rapids, waterfalls or when water levels are low and the river is unnavigable. Portage distances may vary from a few hundred metres on the flat, to several kilometres over hilly terrain during races like the Dusi Marathon. Portage brings added demands and requires canoeists to train for both canoeing and running.[12]

Measurement of heart rate is a relatively simple and convenient way of monitoring and setting training intensity and has become popular with runners who do not have access to sophisticated tests, like the measurement of oxygen consumption and lactate threshold. Canoeists have also started using heart rate monitors to guide their training. The problem is that although training heart rate zones are well defined for running and cycling, there is little information about the use of heart rate training zones for arm exercise. Presently canoeists are using heart rate target zone-based guidelines provided for running. This assumes that the cardiac response to exercise of increasing intensity is the same for lower and upper limbs. It also assumes that the respiratory response to exercise in the erect position, while running, is the same as when seated, in a canoe. Any variation in cardiorespiratory responses while canoeing may affect the heart rate to exercise intensity relationship upon which guidelines for lower-limb training have been developed.

Intuitively it could be argued that maximal heart rate (HR_{max}) and hence the heart rate zones should be the same for upper and lower-limb exercise. The published literature is contradictory. Upper-limb exercise is reported to evoke a cardiovascular response different from that of lower-limb exercise, with heart rate and oxygen consumption at any submaximal exercise intensity being higher with arm exercise.[2,9,14,16] Conversely, in most texts, HR_{max} with arm exercise is given as being on average 10 - 13 beats/minutes lower than HR_{max} with leg exercise,[13,14,17] with the heart rate at any given submaximal intensity being higher with arm exercise and the HR_{max} being lower. The implication of this is that the range of heart rates in a training zone may be narrower for arm exercise than for leg exercise and it is suggested that workloads considered appropriate for leg training should be reduced by 50 - 60% for arm training.[10]

Maximal oxygen consumption (VO_{2max}) is also reported to be lower with upper-limb exercise, with sedentary subjects achieving only 70% of their running VO_{2max} when performing upper-limb exercise.[1,6] Canoeing uses a smaller total muscle mass than running and this may explain differences between upper and lower-limb exercise oxygen consumption.[14,17] The reduction in HR_{max} and VO_{2max} with upper-limb exercise may not hold in elite canoeists who train at very high intensities. Colli *et al.*[5] as quoted by DalMonte and Leonardi,[7] found that the best canoeists can achieve the same VO_{2max} on a kayak ergometer and a treadmill, while this was not the case for medium-level athletes.

The aim of this study was to investigate the relationship of heart rate and oxygen consumption when performing upper-limb or lower-limb exercise, in canoeists who compete regularly, so that advice can be formulated for the use of heart rate monitors for upper-body exercise.

Methods

The study was undertaken with the approval of the Bio-Ethics Committee of the University of KwaZulu-Natal and all participants gave signed informed consent prior to participation in the study.

Thirteen male paddlers involved in local and national competition were recruited from a local canoe club. They were required to have been paddling for at least the past 5 years and to have been actively paddling and participating in races over the previous 6 months. The average age of the athletes was 33.8 ± 10.0 years, with a range of 19 - 51 years of age. Their average height was 1.79 ± 0.06 m, with a range between 1.71 m and 1.91 m, and their average weight was 81.9 ± 10.7 kg, with a range from 57.2 kg to 101.1 kg. There was 1 junior and 1 master age group paddler. Exclusion criteria included recent upper or lower-limb injury, history of any cardiorespiratory disease in the preceding 3 months and the need to take any medication affecting heart rate.

Subjects attended a familiarisation session in which they paddled on the kayak ergometer and ran on a treadmill. They were randomised using a pseudo random number generator, and assigned to perform a VO_{2max} test on either the kayak ergometer or the treadmill. Five to 7 days later they returned at the same time of day to perform a VO_{2max} test on the other apparatus. Participants were asked not to train on the day before testing, to follow a similar dietary intake on both days of testing and to exclude caffeine intake prior to testing. Ambient temperature in the laboratory was maintained at 20 - 21°C during testing.

Kayak ergometry was performed on the K1 Erg (Garran, Australia).[20] This is a wind-braked machine developed for the Australian Institute of Sport. It has a built-in strain gauge allowing computerised measurement of force generated during each stroke. The length and duration of each stroke is measured and thus the power output per stroke can be computed. The VO_{2max} test protocol was individualised for each subject. After a warm up of 5 minutes at a self-selected intensity, a 10-second all-out maximum test was performed from which the peak power output was noted in watts. The peak power output was divided by 20 and rounded to the nearest 5 W, and the result was used as the power increment for the VO_{2max} test. When heart rate had returned to within 5 beats per minute of resting levels, the VO_{2max} test commenced. This protocol was derived from several pilot studies and the power increments are similar to those used in other studies using the K1 ergometer.[3]

Following a 5-minute warm-up at below 40 W, subjects started by paddling at 40 W for 3 minutes and the workload was increased by the pre-determined power increment every minute thereafter to exhaustion. The power output generated during the test was displayed in real time on a laptop computer screen. For each increment, subjects were told the power output that they had to achieve for the next minute. To do this they had to increase the force used during each stroke and/or increase the stroke rate. The test ended when the subject was no longer able to maintain the required power output. Once completed, the athlete was instructed to warm down by paddling at a low intensity. Data on the length, duration and force profile of each stroke and the stroke rate were recorded.

Treadmill testing was performed on a Power Jog GX100 (Sport Engineering Ltd, Birmingham, England) treadmill using a standardised incremental protocol which increased speed and gradient every minute to exhaustion after a 5-minute warm-up at 8 $km.h^{-1}$ and no gradient.[12]

During the VO_{2max} tests, measurements of oxygen consumption (VO_2), carbon dioxide production (VCO_2), exhaled tidal volume (VTex), expiratory minute volume (V'E), respiratory rate (RR), oxygen pulse, the ventilatory equivalents of oxygen (EqO_2), carbon dioxide ($EqCO_2$) and metabolic equivalent (MET) were obtained by computerised open circuit spirometery (Xycon Champion, version 4.3 Jaeger, Wuerzburg, Germany). A computerised 2-point gas calibration was performed daily against a known concentration of carbon dioxide and nitrogen and a computerised volume calibration was also performed. Heart rate was monitored using a Polar Electro heart rate monitor (Kemple, Finland) interfaced to the spirometer. Data were averaged over the last 30 seconds of each stage.

Subjects were tested at the same time of day to exclude the possibility of variation due to diurnal changes in hormone concentrations.

Statistical analysis was by 2-tailed paired *t*-test for comparison of means, after checking for the normality of distribution of the data using the Kolmogorov and Smirnov test. Alpha was set at 5%. The relationship between 2 variables under the different testing circumstances was examined using linear regression.

Results

The mean maximal spirometric and heart rate data obtained on the kayak ergometer were significantly lower for all parameters measured, except for exhaled tidal volume and oxygen pulse. Maximum respiratory rate was not statistically significantly higher on the kayak ergometer (Tables I and II).

HR_{max} on the kayak ergometer was 97% of that on the treadmill, and kayak VO_{2max} was 80% of treadmill VO_{2max}. The mean

TABLE I. The maximun metabolic equivalent (MET), oxygen consumption (VO_2), carbon dioxide production (VCO_2), respiratory exchange ratio (RER) and oxygen pulse (O_2 pulse) obtained on the kayak and treadmill ergometers, expressed as means and 1 SD, with 95% confidence intervals (CIs).

	Kayak	95% CI	Treadmill	95% CI	*P*-value
MET	12.0 ± 2.4	9.6 - 13.3	14.7 ± 1.7	13.5 - 15.9	0.0002
VO_2 (ml.kg^{-1}.min^{-1})	41.9 ± 8.3	33.5 - 46.4	51.5 ± 5.8	47.2 - 55.7	0.0003
VO_2 (ml.min^{-1})	3511 ± 691	2819 - 3886	4342 ± 677	3717 - 4838	0.0005
VCO_2 (ml.min^{-1})	3929 ± 803	3126 - 4366	5253 ± 905	4348 - 5745	0.0003
RER	1.12 ± 0.06	1.06 - 1.15	1.18 ± 0.05	1.14 - 1.21	0.0054
HR (beats.min^{-1})	172.1 ± 8.7	163.4 - 176.8	177.8 ± 7.1	171.2 - 182.1	0.0036
O_2 Pulse (ml.beats^{-1})	20.4 ± 3.9	16.5 - 22.5	24.3 ± 4.0	20.9 - 27.2	0.001

TABLE II. The maximum minute volume (V'E), exhaled tidal volume (VTex), respiratory rate (RR), oxygen equivalent (EqO_2) and carbon dioxide equivalent ($EqCO_2$) obtained on the kayak and treadmill ergometers, expressed as means and 1 SD.

	Kayak	95% CI	Treadmill	95% CI	*P*-value
V'E (l.min^{-1})	116.9 ± 19.7	97.2 - 127.6	141.2 ± 21.5	119.7 - 152.9	0.0005
VTex (l)	2.546 ± 0.718	1.828 - 2.937	3.062 ± 0.457	2.605 - 3.310	0.0512
RR (breaths.min^{-1})	48.2 ± 13.5	34.7 - 55.6	46.3 ± 5.5	40.8 - 49.3	NS
EqO_2 (l.l^{-1})	33.0 ± 3.9	29.1 - 35.1	31.4 ± 3.1	28.3 - 33.0	NS
$EqCO_2$ (l.l^{-1})	29.5 ± 3.1	26.5 - 31.2	26.6 ± 2.4	24.3 - 27.9	0.0034

HR_{max} on the kayak ergometer was 5.9 beats per minute lower than on the treadmill, with a median difference of 4 beats per minute. Two subjects obtained the same heart rate on both apparatus. The heart rates of 10 of the 13 subjects were within 8 beats of their treadmill HR_{max}. Three subjects had differences of 11, 15 and 18 beats per minute and their respiratory exchange ratios (RERs) were 1.07 (N = 1) and 1.02 (N = 2) suggesting that they may not have achieved maximum exertion and hence maximum heart rate.

The relationship of heart rate to oxygen consumption on the kayak ergometer and treadmill is shown in Fig. 1. The slopes of the regression equations are similar. At any given oxygen consumption, a measure of exercise intensity, heart rate is higher with arm exercise and at any given heart rate, oxygen consumption will be higher with leg exercise. The linear regression equations were used to calculate heart rate at oxygen consumptions of 10 - 70 ml.kg^{-1}.min^{-1} at 5 ml.kg^{-1}.min^{-1} increments. The heart rates derived for kayaking were significantly higher than for treadmill running, ($p < 0.0001$).

Heart rate training zones are used to equate exercise intensity and are based on the linear relationship of heart rate and oxygen consumption. The relationship between percentage HR_{max} and percentage VO_{2max} is examined in Fig. 2. The trend lines are very similar, with exercise on the treadmill eliciting a slightly higher percentage of VO_{2max} up to 91% of HR_{max}.

Many canoeists are presently using lower-limb HR_{max} when calculating their heart rate training zones for canoeing. To examine the effect of this, the percentage of arm VO_{2max} used at any percentage of arm HR_{max} was plotted and compared with the percentage of arm VO_{2max} achieved when the arm heart rate is expressed as a percentage of the leg HR_{max} (Fig. 3). The regression lines indicate that when basing canoeing training on a percentage of leg HR_{max}, a higher percentage of arm VO_{2max} will be achieved than when heart rate zones are based on arm HR_{max}. The regression equations were used to calculate the percentage VO_{2max} utilised at 60, 70, 80 and 90%

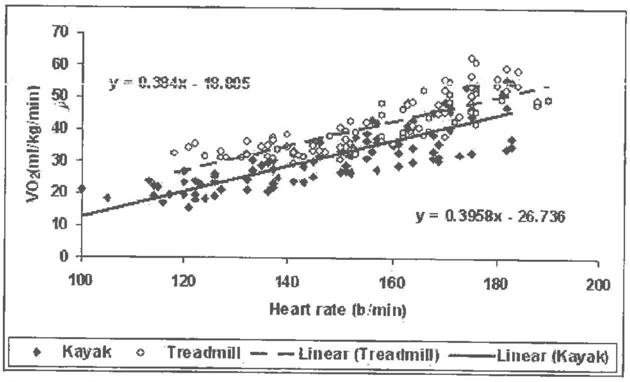

Fig. 1. Scatterplot of the relationship between oxygen consumption and heart rate on the kayak ergometer and the treadmill. The linear regression equations are given.

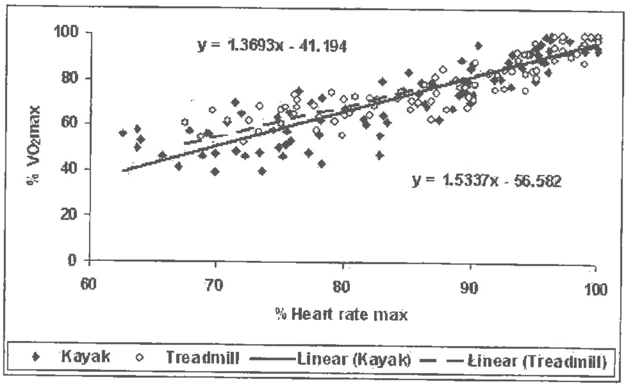

Fig. 2. Scatterplot of the relationship between percentage HR_{max} and percentage leg $VO2_{max}$ when exercising on the kayak ergometer and the treadmill. The regression lines and equations are shown.

of arm-derived HR_{max} and leg-derived HR_{max} when paddling. Use of leg-derived HR_{max} to set training intensities for canoeing would result in the paddler training at a $\%VO_{2max}$ that was 7.2% higher at 60% leg HR_{max}, 5.7% at 70% leg HR_{max}, 4.3% at 80% leg HR_{max}, and 2.8% at 90% leg HR_{max}.

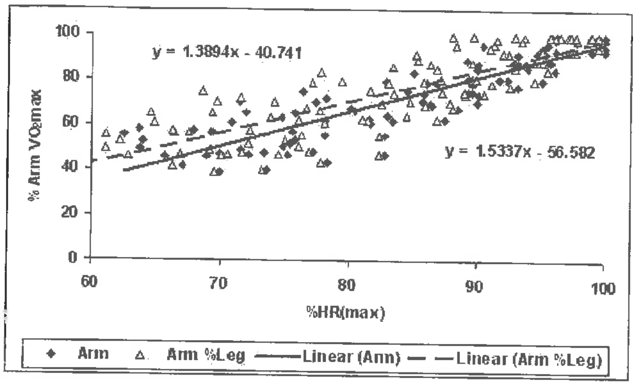

Fig. 3. Scatterplot of the relationship between the percentage of arm $VO2_{max}$ used at any percentage of arm HR_{max} and the relationship of the percentage of arm VO_{2max} achieved when the arm heart rate is expressed as a percentage of the leg HR_{max}. The regression lines and equations are shown.

The maximal exhaled tidal volume with arm exercise was less than with leg exercise and this approached significance, with the respiratory rate showing a trend of being slightly higher than with leg exercise although this too was not significant. The relationship of respiratory rate and METs is shown in Fig. 4.

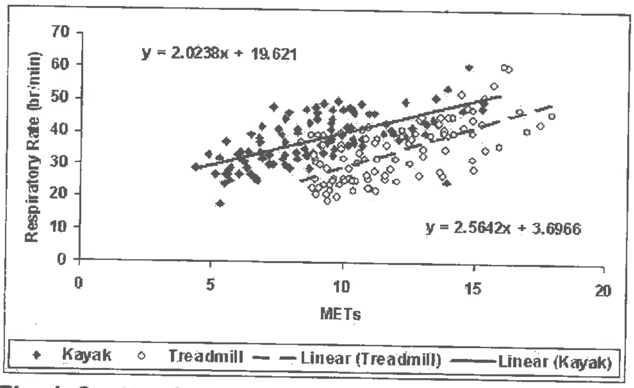

Fig. 4. Scatterplot of the respiratory rate and metabolic equivalents when exercising on the kayak ergometer and treadmill. The regression equations are shown.

At any given MET, which is a measure of submaximal exercise intensity, the respiratory rate on the kayak ergometer is increased. At lower exercise intensities the increase in rate is greater than at higher intensities. Based on the regression equations, over a range of 4 - 20 METs, respiratory rate on the kayak ergometer was significantly increased by 13.8 ± 5.1 breaths per minute ($p < 0.0001$). The difference in tidal volume approached significance at maximal exercise.

The relationship between tidal volume at different METs is shown in Fig. 5. At any given MET the tidal volume was larger when running on the treadmill. The regression equations were used to calculate tidal volumes over a range of 4 - 20 METs. Tidal volumes were significantly reduced when kayaking, ranging from 439 ml at 4 METs to 690 ml at 20 METs ($p < 0.0001$).

The relative effects of a reduced tidal volume and increased respiratory rate during submaximal exercise can be examined by investigating the relationship between minute volume and METs (Fig. 6). Minute volume on the kayak ergometer is higher than on the treadmill for all but the highest intensities of exercise. The regression equations were used to calculate minute volumes over a range of METs. The differences in minute volume were statistically significant when limited to the range of METs achieved on the kayak ergometer ($p = 0.0109$).

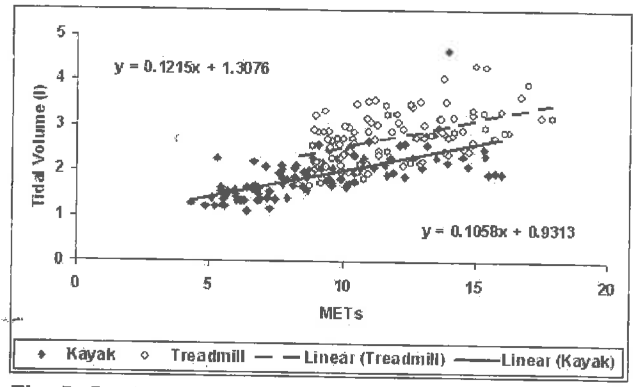

Fig. 5. Scatterplot of the relationship of tidal volume to METs on the kayak ergometer and treadmill. The linear regression equations are shown.

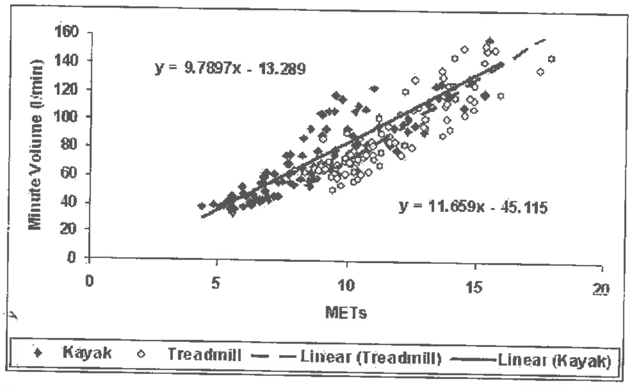

Fig. 6. Scatterplot of the relationship between minute volume and METs on the kayak ergometer and the treadmill. The regression equations are shown.

Discussion

The main findings of this study are that the average HR_{max} and VO_{2max} are lower when kayaking and that the relationship between percentage VO_{2max} and percentage HR_{max} is similar with kayaking and treadmill running. Furthermore, the differences in this cohort of subjects are such that kayak training based on a percentage of leg HR_{max} would elicit only minor increases in percentage VO_{2max} predicted.

Secondary findings are that when kayaking, tidal volumes are reduced at submaximal exercise intensities with a concomitant increase in respiratory rate and minute volume.

The primary aim of this study was to investigate the relationship of heart rate and oxygen consumption when exercising on a sport-specific kayak ergometer and a treadmill so as to be able to give advice on setting heart rate training zones for kayak training. Evaluation of oxygen consumption and heart rate during upper-limb exercise has usually been performed using arm crank ergometers.[11,15] Arm cranking is not sport specific and does not utilise the same muscle groups, or utilise and recruit muscle groups in the same order or at the same intensity as in canoeing.

Most studies investigate athletes or sedentary subjects who are not used to prolonged or all-out upper-limb exercise. This may result in subjects tiring during arm ergometry before reaching HR_{max} and may explain the large differences between arm and leg HR_{max}. The studies that have investigated trained canoeists have generally reported smaller differences.[5,7]

In this study of a group of regular canoeists of differing ability, from regular club participation to provincial representation, arm HR_{max} was on average 5.9 beats.min^{-1} lower than, or 97% of, the leg HR_{max}. Differences in subjects ranged from 0 to 18 beats.min^{-1} with a median of 4 beats.min^{-1}. It is likely, based on the RERs of less than 1.1 at cessation of exercise, that the 3 subjects whose arm $HR_{max's}$ were 11 - 18 beats.min^{-1} lower did not reach either their HR_{max} or VO_{2max}. It could also be argued that these are valid data and that there is a subset of canoeists who are unable to approximate either their leg HR_{max} or VO_{2max} when canoeing. Another possible explanation is that the difference in HR_{max} and VO_{2max} is related to the relative levels of arm and leg fitness.

In high-level canoeists, VO_{2max} (ml.kg^{-1}.min^{-1}) obtained on a cycle ergometer was found to be 7.3% higher than on a kayak ergometer. Similarly a 6.5% difference in VO_{2max} expressed in l.min^{-1} was noted between treadmill and kayak ergometry and other studies have shown the percentage of leg VO_{2max} achieved by paddlers performing upper-limb exercise to range from 77 to 100%.[4,18,19,21] In this study, VO_{2max} on the kayak was lower than on the treadmill for the majority of subjects, with the average kayak VO_{2max} being 80% of the treadmill VO_{2max}. Four subjects, however, had kayaking and treadmill maximum heart rates that were the same or differed by only 1 beat.min^{-1}. In 3 of the 4 subjects their VO_{2max} differed by less than 1 ml.kg^{-1}.min^{-1} or 150 ml.min^{-1}. The fourth subject had the highest VO_{2max} on the treadmill, of 62.7 ml.kg^{-1}.min^{-1} but could only achieve 47.0 ml.kg^{-1}.min^{-1} on the kayak ergometer, a 25% difference.

This difference in mean VO_{2max} may be due to the utilisation of a smaller muscle mass, and the reduced HR_{max}. The observation of increased heart rate at submaximal intensities with upper-limb exercise may be on the basis of diminished venous return with exercise in the seated position. In kayaking the leg muscles are used to a far lesser degree than in running. Associated with this would be a reduction in venous return from the legs. The seated posture, with the hips flexed to about 110°, increases intra-abdominal pressure which is further increased by abdominal muscle contraction during trunk rotation. This increase in abdominal pressure will tend to reduce venous return, necessitating an increase in heart rate to maintain an appropriate cardiac output.[8]

This posture may also affect ventilation, through diminished diaphragmatic excursion and may account for the reduction in tidal volume and increase in respiratory rate noted at submaximal exercise intensities. The increased respiratory rate will increase the work of breathing and may in part account for the increased heart rate at different submaximal exercise intensities. At maximal exertion on the kayak, the ventilatory equivalents of oxygen (the volume of air that must pass through the lungs to extract 1 litre of oxygen) and carbon dioxide are 5.2% and 10.8% higher than on the treadmill, while the minute volume is reduced by 17.2%, again suggestive of the increased work of breathing on the kayak ergometer.

The relationship between the percentage of VO_{2max} achieved at a given percentage of HR_{max} is similar for kayaking and treadmill running so the principles followed for using HR_{max} to guide training intensity should hold. The question then is whether maximal heart rates achieved with leg exercise are valid for formulating training intensities for kayaking. Training at intensities based on leg HR_{max} will elicit a higher percentage of arm VO_{2max}. As the kayak HR_{max} in this study is 97% of the treadmill HR_{max} the difference is not as great as might have been expected. Therefore training zones based on leg HR_{max} will in general be suitable with the proviso that a minority of canoeists may have markedly lower upper-limb VO_{2max}. To accommodate this minority a simple canoeing test that can be conducted on water, and that will elicit maximal canoeing-induced heart rate needs to be developed.

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