

**A COMPARISON OF UPPER AND LOWER LIMB EXERCISE IN CANOEISTS USING THE
HEART RATE AND OXYGEN CONSUMPTION RELATIONSHIP.**

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ABSTRACT

The heart rate achieved with maximal upper limb exercise is quoted as being on average thirteen beats per minute lower than when performing maximal leg exercise. Many canoeists use heart rate monitors during training and seek advice on setting their heart rate training zones. Existing guidelines are based on lower limb-derived heart rates, which may not be appropriate. As canoeists use predominantly their upper limbs during canoeing, it was hypothesized that as their upper limbs are trained, they may achieve heart rates and oxygen consumption similar to those achieved with lower limb exercise. The purpose of this investigation was to compare the relationship between heart rate and oxygen consumption when exercising on either a kayak ergometer or treadmill.

Fifteen volunteer canoeists, who compete regularly, were recruited by convenience, purposive sampling and randomly allocated to a VO_2max test using open circuit spirometry, on either a kayak ergometer or treadmill. They returned within 5 to 7 days for a VO_2max test on the other apparatus. Their heart rates were also measured during these activities. The heart rate oxygen consumption relationship for upper and lower limb exercise was then analysed.

Maximum heart rate was on average only 6 beats per minute lower with upper limb exercise, with some subjects achieving the same or very similar HR_{max} ; the median difference in heart rate maximum was only 4 beats per minute. Although the response of heart rate and oxygen consumption to kayaking and running was similar at any given workload, the heart rate on the kayak was about 8 beats per minute higher at

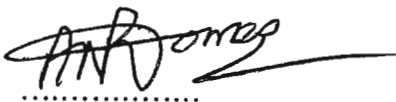
any submaximal workload. VO_2max on the kayak was lower than on the treadmill. At any metabolic equivalent, the tidal volume was lower on the kayak and there was a lower respiratory rate on the treadmill. At any tidal volume, the metabolic equivalent was lower on the kayak ergometer. The minute volume on the kayak was higher than on the treadmill, for all but the highest intensities of exercise. Using the leg heart rate max to determine the training zones, a slightly higher (negligible) percentage of arm VO_2max is achieved at any given percentage heart rate.

Kayakers who train regularly, appear to be able to attain similar maximum heart rates with upper and lower limb exercise, but a lower VO_2max when exercising with their arms. The heart rate oxygen consumption response is the same for upper and lower body exercise; and a reduced HRmax and increased heart rate at any submaximal workload do not appear to apply to canoeists.

It is therefore concluded that heart rate training zones based on leg HRmax are suitable for kayak training. This study has helped distinguish the difference between the heart rates of the upper and lower limbs at any given oxygen consumption in canoeists. The benefits of performing this study have also been to provide better advice to canoeists on how to train using heart rate monitors.

DECLARATION

This study represents original work by the author and has not been submitted previously to this or any other University. I acknowledge the assistance of Professor Maurice Mars.

A handwritten signature in black ink, appearing to read 'Neil Gomes', with a long horizontal flourish extending to the right. Below the signature is a dotted line.

NEIL GOMES

2003

DEDICATION

This dissertation is dedicated to my friend Sergio De Sousa, who died whilst participating in the Argus International Cycle Tour, March 2001.

PRESENTATIONS

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The late Mr Adriano Gomes and Mrs Aida Gomes: who despite their death and disabling illness respectively, continue to inspire me.

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CHAPTER 1

INTRODUCTION

Canoeing is a growing sport in South Africa. The majority of South African canoeists participate in marathon canoeing, with race distances varying from 13 km to 200 km. There may also be associated portages of up to 7 km. This makes different demands of the paddlers, as portages of these distances require the kayakers to train both their upper and lower limbs. The use of heart rate monitors to set training heart rate zones has become popular, and is now widely used in canoeing. Although the heart rate training zones have been well defined for lower limb training, there is little information about the use of heart rate training zones for arm exercise. Presently, anecdotal evidence suggests that many local canoeists are using their lower limb or age-derived heart rate maximum to set their training zones for canoeing.

It has been stated that athletes' maximum heart rates are on average ten to thirteen beats per minute lower when exercising using their upper limbs than when using their lower limbs. This is probably due to the larger muscle volume in the legs (Sleamaker, 1989; Miles, *et al*, 1989; McArdle, *et al*, 1996: 405). Yet, canoeists exhibit comparatively greater upper body strength and anaerobic capacity due to the predominant use of their upper limbs during paddling (Tesch, 1983). Furthermore, when comparing upper limb and lower limb exercise at any given submaximal exercise intensities, heart rates and oxygen consumptions have been shown to be higher with upper limb exercise (Eston and Brodie, 1986; Aminoff, *et al*, 1998).

These two observations taken together suggest that heart rate training zones for upper limb exercise may be different for upper and lower limb exercise.

According to Franklin (1989), an arm exercise prescription that is based on maximal heart rate derived from leg testing may result in an inappropriately high target heart rate for arm training, and workloads considered appropriate for leg training will generally need to be reduced by 50-60 % for arm training. Pimental, *et al* (1984) also suggested that exercise prescriptions based on heart rate alone may need to be modified for upper body exercise.

One study of elite canoeists however, has shown canoeists' maximum heart rates with upper limb arm cranking exercise to be higher than their lower limb exercise maximum heart rate (DalMonte and Leonardi, 1976). Regular participation in canoeing at elite level may therefore lead to adaptations that allow upper limb exercise in canoeists to elicit similar heart rate and oxygen consumption responses to lower limb exercise. It is not known if these adaptations occur in non-elite paddlers.

The purpose of this investigation was to examine the heart rate and oxygen consumption relationship in regular canoeists of varying ability to determine whether separate upper limb specific heart rate training zones are required for canoeing.

CHAPTER 2

LITERATURE REVIEW

Canoeing has received relatively little attention from sports scientists and there is a paucity of available peer reviewed literature. In South Africa, recent research has focused on issues pertaining to the Dusi Canoe Marathon (Appleton and Baily, 1990; Mars, 1995; Mars and Foreman, 2000; Farman and Mars, 2002), profiling of junior sprint canoeists (McKune, et al, 2003), and psychological preparation (Terblanche, et al, 2003). Apart from the work of Mars (1995) on the energy costs of portage, none of the local research to date has provided guidelines to canoeists to assist them with training.

With the acceptance of heart rate monitoring for running marathon training, it is not surprising that canoeists have sought to use this aid to guide canoeing training. Although the heart rate training zones have been well defined for lower limb training, there is little information about the use of heart rate training zones for arm exercise.

As previously noted in Chapter 1, the standard physiology texts suggest that in healthy individuals, the maximum heart rate achieved with arm exercise is 10 – 13 beats per minute lower than with leg exercise (McArdle, *et al*, 1996: 405), and that arm peak heart rate is 8 % lower than leg peak heart rate (Keteyian, *et al*, 1994). The implications of this are, that if heart rate maximum with leg exercise is higher than with arm exercise, any submaximal heart rate, for example 60 % heart rate max, will be at a higher absolute value with leg exercise,

than with arm exercise. It is however, also well documented that at any given submaximal workload, heart rate is higher with arm exercise (Miles, *et al*, 1989, and Pendergast, 1989). The increase in upper limb induced heart rate at submaximal exercise raises the possibility that the heart rate training zones may be narrowed for arm exercise in canoeists.

2.1 Upper limb versus lower limb exercise

The published studies have generally used arm cranking ergometry for testing. Few studies were found to have tested canoeists on kayak ergometers. It has been shown that at the same power output, arm ergometry elicits greater cardiorespiratory, metabolic (Jensen-Urstad, *et al*, 1993; Peng, *et al*, 1998), and perceptual responses than leg ergometry (Kang, *et al*, 1999). Casaburi, *et al* (1992) found that both dynamic and steady state responses of ventilation and gas exchange to arm exercise did not differ substantially from those of leg exercise, so long as the power output did not elevate blood lactate levels. Ishida, *et al* (1994) found that minute volume and heart rate at the onset of arm exercise was greater than with leg exercise in both voluntary and passive conditions, regardless of the muscle mass. They suggested that this was due to different neurogenic responses. During submaximal exercise, Faria and Faria (1998) also showed that cardiorespiratory responses to upper body exercise did not differ significantly from those of lower body exercise, as long as the upper and lower body workloads were set at equal relative intensities.

Positioning of the arms, above, at, or below heart level, did not appear to affect the submaximal or maximum responses to arm exercise (Cummins and Gladden, 1983), and no

differences were found in arm work at submaximal or maximal effort, between sitting and standing (Vokac, *et al*, 1975). However, when arm exercise was performed in the heat, the heart rate was 6 beats per minute greater than when performed in the cool (Pivarnik, *et al*, 1988).

Kozlowski, *et al* (1983) found serum growth hormone concentration after arm exercise to be significantly greater than after leg exercise. They proposed that neural afferent signals sent by muscle 'metabolic receptors' participate in the activation of growth hormone release during physical exercise.

2.2 Anaerobic threshold

In a study by Pendergast, *et al* (1979), lactate threshold occurred at significantly lower arm workloads than anaerobic threshold. According to Nikolic and Todorovic (1984), anaerobic threshold may be determined by monitoring the ventilation changes during progressive exercise and may serve as an index of cardiorespiratory performance capacity. Further to this, it appears that greater demands are made on anaerobic energy supply during arm exercise (Jensen-Urstad, *et al*, 1993, and Jensen-Urstad, *et al*, 1995). Nikolic and Todorovic (1984) found that pulmonary ventilation at anaerobic threshold was lower during arm than during leg exercise in both females and males.

2.3 Heart rate

2.3.1 Regulation of heart rate

Increased heart rate during exercise is due to sympathetic activity and withdrawal of parasympathetic tone (Hartley, 1992). Blocking the autonomic system with propranolol can slow maximal heart rate during exercise, although this has little or no effect on maximal oxygen intake. This suggests that maximum stroke volume has considerable reserve. (Hartley, 1992). The higher absolute heart rate reported during submaximal arm exercise versus leg exercise may also be mediated by cardiac innervation (Keteyian, *et al*, 1994). However, according to Jensen-Urstad, *et al* (1993), the increase in blood lactate at submaximal exercise intensities whilst performing arm and leg exercise is caused by factors other than beta-adrenoceptor stimulation. The vasoconstrictor effects of high levels of muscle sympathetic nerve activity do not affect blood flow to human skeletal muscle exercising at moderate intensities (Strange, 1999).

2.3.2 Effect of age on heart rate

Maximal heart rate diminishes with age, as does $\text{VO}_{2\text{max}}$. This is not necessarily causal as the heart rates of sedentary and endurance-trained individuals are similar at any age, despite large differences in $\text{VO}_{2\text{max}}$ (Janssen, 1987). Furthermore, up to the sixth decade in healthy men, age is not necessarily associated with a decline in physical work capacity in exercises using relatively small muscle groups (Aminoff, *et al*, 1996).

2.4 Oxygen consumption

Reybrouck, *et al* (1975) compared arm, leg and combined arm and leg ergometry at submaximum work intensities. No significant differences in VO_2 were found between the three exercise groups but differences were observed for heart rate, ventilation, and cardiac output. It has been thought that to some extent, $\text{VO}_{2\text{max}}$ depends on the exercising muscle mass (Bergh, *et al*, 1976). Yet, Miles, *et al* (1989) suggest that the central and peripheral responses to either upper or lower body exercise appear to be independent of the muscle mass, but rather directly related to the ergometer-specific relative exercise intensity. Furthermore, Pendergast (1989) states that the limitations of VO_2 adjustment in the arms are not due to cardiac or muscle blood flow limitations, but may be due in part to sluggish kinetics of oxidative metabolism and increased glycolysis. This results in lactic acid production and lactate and proton accumulation in blood, which would lead to a cardiovascular and respiratory pressor effect.

The possible effect of upper limb training on $\text{VO}_{2\text{max}}$ was investigated by Pendergast, *et al* (1979). The upper limb $\text{VO}_{2\text{max}}$ of kayakers was found to be 50 % higher than that of a sedentary group while the lower limb $\text{VO}_{2\text{max}}$ of the two groups was not different. This suggests that the normal increases in $\text{VO}_{2\text{max}}$ associated with training hold true for upper limb exercise. The relationship of upper and lower limb $\text{VO}_{2\text{max}}$ in canoeists who have to train for both upper and lower limb use in race situations has not been reported.

According to Washburn and Seals (1983), the use of continuous and discontinuous protocols for determining VO_2peak during arm cranking provided comparable results.

2.5 Heart rate – oxygen consumption relationship

The prescription of exercise intensity for different training effects is best based on lactate threshold and percentage of VO_2max (McArdle, *et al*, 1996: 405). Not many people have access to these tests on a regular basis. As heart rate response and oxygen consumption are linear until maximum oxygen consumption is reached, there is a predictable relationship between percentage VO_2max and percentage heart rate max, regardless of gender, fitness level, or age. The error in estimating the percent VO_2max from the percent HRmax , or vice versa, is approximately 8 % (McArdle, *et al*, 1996: 405). As a result of this intrinsic relationship, it is only necessary to monitor heart rate to estimate the exercise stress or % VO_2max . This relationship between percent VO_2max and percent HRmax is assumed to be essentially the same for arm or leg exercises among healthy individuals. This assumption may not be valid because of the reported reduction in HRmax with upper limb exercise and the increase in heart rate at submaximal work intensities with upper limb exercise.

Present guidelines for the use of HRmax to set training zones for upper limb exercise suggest subtracting 13 beats from the age-predicted HRmax (i.e: $220 \text{ beats per min} - \text{age} - 13 \text{ beats per minute}$) (McArdle, *et al*, 1996: 405). As already stated in chapter 1, according to Franklin (1989), an arm exercise prescription that is based on maximal heart rate derived from leg testing may result in an inappropriately high target heart rate for arm training; and workloads

considered appropriate for leg training will generally need to be reduced by 50-60 % for arm training. Pimental, *et al*, (1984) also suggested that exercise prescriptions based on heart rate alone may need to be modified for upper body exercise.

This however, has not been shown to be valid for elite canoeists, where the upper limb exercise heart rates were shown to be higher than their lower limb exercise at maximum oxygen consumption (DalMonte and Leonardi, 1976). The subtraction therefore becomes inappropriate.

As a general rule, aerobic capacity improves if the heart rate is increased to 70 % of maximum. This represents moderate exercise. During leg exercise (walking or running), this increase is equivalent to about 55 % of VO_2max , or to a heart rate of 130 to 140 beats per minute for a 20 to 30 year old. An alternative, and equally effective method for establishing training threshold is to exercise at about 60 % of the difference between resting and maximum heart rates, the heart rate reserve (McArdle, *et al*, 1996). This however, tends to provide somewhat higher values.

As aerobic fitness improves, heart rate is reduced at any given oxygen uptake. It is common for the submaximal heart rate to be lowered by 10 to 20 beats per minute as a result of aerobic training and exercise intensity should periodically be increased to attain the desired heart rate (McArdle, *et al*, 1996).

The current literature on regular canoeists with regard to their heart rate-oxygen consumption relationship when on the arm crank ergometer, comparing upper limb with lower limb exercise, has been presented. The anaerobic threshold and its relevance to canoeists, as well as the regulation, and the effect of age on heart rate have been commented on. Studies relating to oxygen consumption with arm cranking have also been included in this review. Finally, it was established that there are no studies relating to specific heart rate training zones for canoeing, hence the need for a study of this nature.

CHAPTER 3

METHODS

3.1 Selection criteria

Currently active canoeists were recruited from a local canoe club. They were required to have been paddling for at least the past five years and to have been actively paddling over the previous 6 months. Their ages ranged between 18 and 55 years old.

3.2 Exclusion criteria

Exclusion criteria included recent upper or lower limb injury, history of any cardio-respiratory disease in the preceding three months and the need to take any medication that affects heart rate.

3.3 Apparatus

Computerised open circuit spirometry (Jaeger Oxycon Champion, version 4.3 – CE 0434), was used to measure oxygen consumption, carbon dioxide production, tidal volume, respiratory rate, minute volume, oxygen pulse, and the ventilatory equivalents of oxygen and carbon dioxide (see Figure 1). A computerised two point gas calibration was performed daily against a known concentration of carbon dioxide in nitrogen, and a computerised volume

calibration was also performed (see Appendix A). Data output were averaged over 30 seconds.

Heart rates were monitored using the Polar Sport Tester heart rate monitor (Electro OY – CE 0537 / GBR 175015.A). The heart rate monitor belt was strapped around the subject's chest, just below the nipple line. The inner surface of the belt was moistened prior to application, as per the manufacturer's instruction. The signal from the belt was monitored on the Polar watch and the telemetric signal was captured and recorded in the spirometer's computer. The heart rate data were averaged over 30 seconds.

The K1 Ergo kayak ergometer - produced for the National Sport Research Program of the Australian Sports Commission - was used. The apparatus consists of a frame on which the athlete is seated. There is a footrest with a foot strap in place of steering pedals. The distance of the seat from the footrest is adjustable so the athlete may sit in the same position he or she would use in a canoe (see figure 2). Using a paddle shaft attached to an air braked flywheel and frame by cords and pulleys, the subject is able to simulate the normal paddling stroke. A pair of photo-electric cells monitor the length of cord passing through two pulleys either side of the fly wheel. This measures the length and duration of each stroke on both sides. There is a strain gauge attached to the seat, which measures the force generated with each stroke. The data from the strain gauge and the photo-electric cells are transferred directly to a laptop computer running proprietary software. The software then computes the stroke rate, the work (force x distance) performed during each stroke, and the power output (force per unit time).

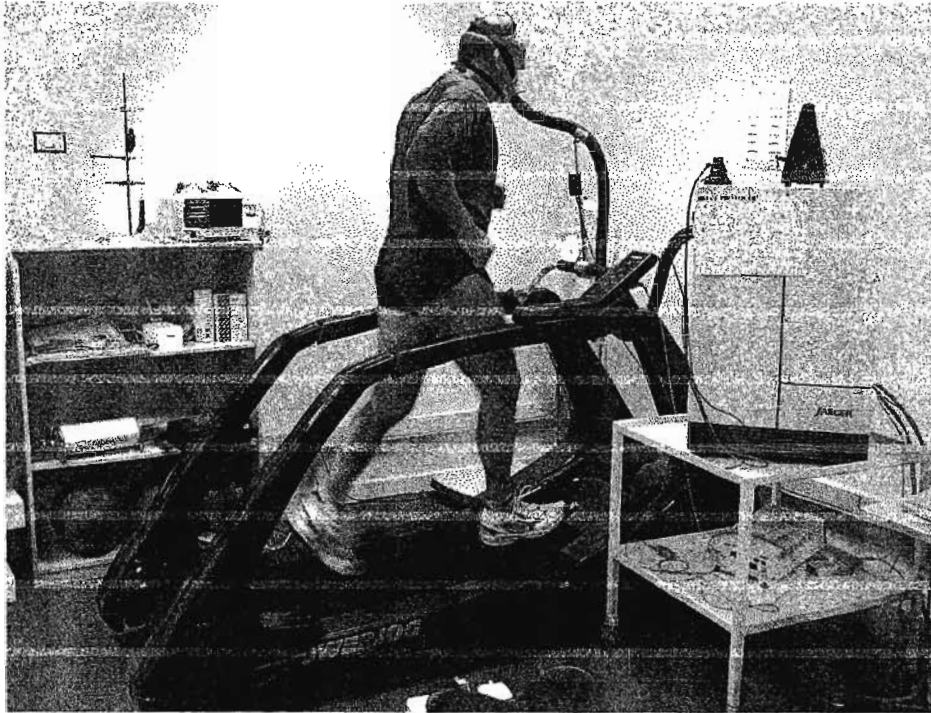


Figure 1: Runner on treadmill, and connected to open circuit spirometry (Oxycon).

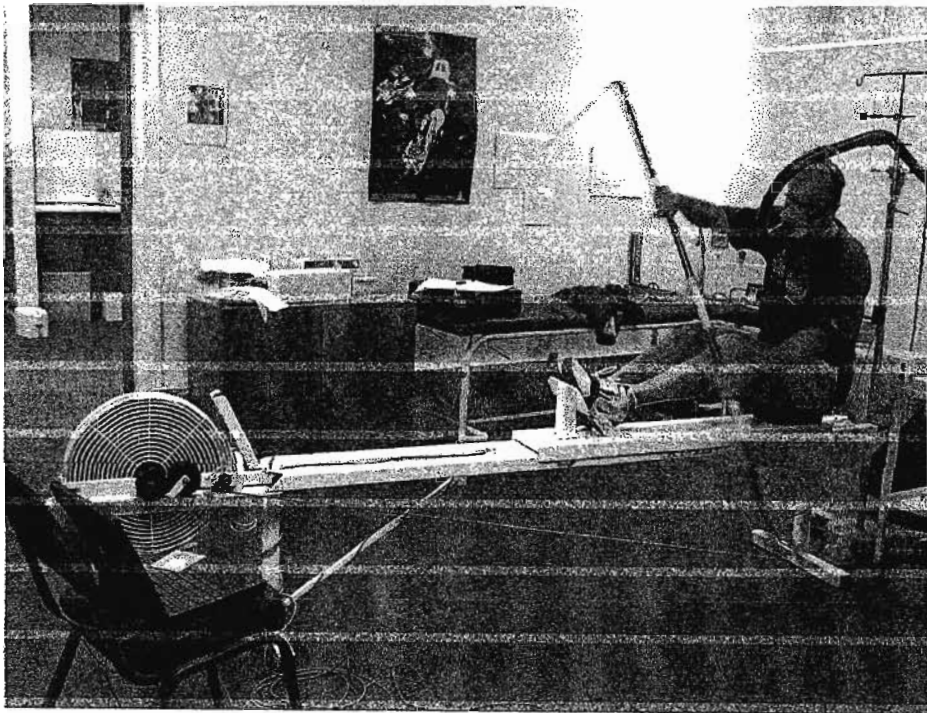


Figure 2: Subject seated and paddling on the K1 kayak ergometer, showing paddle shaft attached by cords to fly wheel.

A PowerJog (GX 100) treadmill was connected by computer to the spirometer (see figure 1). The protocol for the $\text{VO}_{2\text{max}}$ test was entered into the computer, which then automatically changed the gradient of inclination and the speed of the treadmill at the appropriate time intervals.

An AdamLab electronic scale - accurate to 100 g - was used to weigh subjects. Height was measured using a height scale, accurate to 2 mm.

3.4 Research procedure

The study was undertaken with the approval of the Ethics Committee of the Faculty of Medicine. Subjects were allocated to an initial kayak or treadmill group using a computer generated random number list (see Appendix B). At the first visit, athletes were asked to read the information sheet and sign the informed consent form (see Appendix C and D). A history was then taken to ensure that none of the exclusion criteria had been violated. Following the history, the athlete's height, weight, arm span, arm length and handgrip distance (from the outside of the paddle) were measured (see Appendix E).

The height was measured with the athlete barefoot and in shorts, standing facing away from the pole of the height scale, with the heels against the pole. The athlete's head was in a neutral position and the marker was brought down to just touch the crown of the athlete's head. The reading was then taken.

Before the weight was measured, the electronic weight scale was zeroed. The athlete was then weighed with both feet together on the scale, wearing only a pair of shorts. They were asked to remain still until the electronic display panel had stabilised.

Arm span was measured in a straight line, from the tip of the middle (third) left finger to that of the right middle finger, and performed as follows. A reference point was marked on a notice board. The athlete was then asked to face the notice board, with the shoulder abducted to 90°, and to place the tip of his / her left middle finger on this point. With the head turned to one side and the chest flat against the board, the tip of the right middle finger was then placed against the board, with the shoulder abducted 90°. This latter point was marked and the distance between the reference and the second point were measured with a tape measure.

The arm length was measured by having the athlete stand with arms to their sides with their elbows straightened. The distance from the inferior aspect of the acromion to the tip of the middle finger was measured with the elbow in extension.

The athlete was then asked to sit on the kayak ergometer and to take their normal grip on the paddle. They were encouraged to paddle a few strokes, to settle on their comfortable grip. Once they were satisfied they were comfortable, the distance from the outside of the paddle on each side to the lateral aspect of each hand was then measured and recorded.

The heart rate monitor was then strapped to the athlete's chest, after moistening the inner surface, and the Oxycon mask was placed over the athlete's mouth and nose and strapped in

place, ensuring an airtight seal (see Appendix F). Recordings of heart rate and gas exchange were commenced. Subjects then performed either the kayak or treadmill test as determined by randomisation.

Athletes were tested at the same time on each of the testing days to exclude the possibility of variation due to diurnal changes in hormone concentrations.

3.4.1 Kayak

3.4.1.1 Ten second maximum test

The aim of this test was to determine the maximum power output of the subject during a 10 second all out paddle. The subject was asked to perform a mild warm up for approximately five minutes. They then performed a 10 second maximum test, being urged to paddle as hard as they could. The timing of the test was controlled by the K1 ergo software and the computer was paused when the test was complete. The kayak data acquired was automatically captured onto the computer. Various respiratory parameters were measured using computerized open circuit spirometry and the heart rate was recorded (see Appendix G). The athlete was allowed to recover - once the test was complete - to allow the heart rate to return to approximately 80 beats per minute. The peak power output was used to calculate the individualized starting intensity and incremental load for the VO_2 max test.

3.4.1.2 Fifteen minute incremental test

The protocol for the kayak VO_2max test was individualised for each subject and was calculated as follows. The maximum power output obtained from the 10 second test was divided by two, as from pilot studies, it was noted that no subject was able to reach more than half their maximum power output on an incremental test. This figure was used as the target power output and an increment was calculated from the 10 second test. A test with an initial 3 minute period at 40 Watts, followed by (previously calculated) increments every minute was derived, with the whole test lasting 15 minutes.

Once calculated, the 15 minute incremental test was then commenced and the commencement time was noted for exact correlation with the figures on the computer printouts. Subjects initially paddled for 3 minutes, attempting to maintain their power output at 40 Watts. The power output was displayed in real time on the laptop computer screen. At each increment, the subject was told the power output that they had to achieve for the next minute. To do this, they had to increase the force used on each stroke, or the stroke rate. The test ended when the subject was no longer able to maintain the required power output. The termination times were also noted. Once complete, the athlete was instructed to warm down by paddling gently.

The athlete then returned between 5 to 7 days later to repeat the test, this time on the other apparatus.

3.4.2 Treadmill

The athletes were tested on the treadmill using a ramped protocol with increases in gradient and treadmill speed. The intensity was increased every minute after a five minute warm up period. Again, heart rate and respiratory parameters were recorded. The subjects ran to exhaustion. The treadmill protocol is shown in Table 1.

Table 1: Treadmill protocol.

TIME (min)	SPEED (km/h)	GRADIENT (degrees)
0-5	8	3
6-7	9	4
7-8	10	5
8-9	11	6
9-10	12	7
10-11	12	8
11-12	12	9
12-13	12	10
13-14	12	11
14-15	12	12
15-16	12	13

The spirometry data and the kayak ergometer data of each subject were downloaded to Excel. The spirometry data were the averaged data for the last 30 seconds of each interval. Statistical analysis included descriptive analysis, t-tests, and one way analysis of variance with post hoc testing using the Tukey-Kramer test, where appropriate.

CHAPTER 4

RESULTS

Of the 16 canoeists tested, 15 completed the study. One athlete failed to return for the follow-up. Thirteen males and 2 females were tested but the analysis of data included that of the 13 males only. This was due to the significant discrepancies noted between the males and females – in this study and others (Pendergast, *et al*, 1989). The average age of the athletes was 33.8 ± 10.0 years, with a range of 19 to 51 years of age. Their average height was 1.79 ± 0.06 m, with a range between 1.71m to 1.91m and their average weight was 81.9 ± 10.7 kg, with a range from 57.2 kg to 101.1 kg. The arm span averaged 183 ± 10 cm, with a range of 167 cm to 196 cm. The arm lengths varied between 72 cm and 84 cm, with an average arm length of 78.3 ± 4 cm.

4.1 Ten second test

The average peak power achieved during the 10 second maximal test was 322 ± 127.5 W, with the highest peak power achieved being 493 W and the lowest 196 W. The number of strokes taken during the 10 second test ranged from 1 – 11 strokes, with the median and the mean at 9 strokes. The average power per stroke during the 10 second test is shown in figure 3.

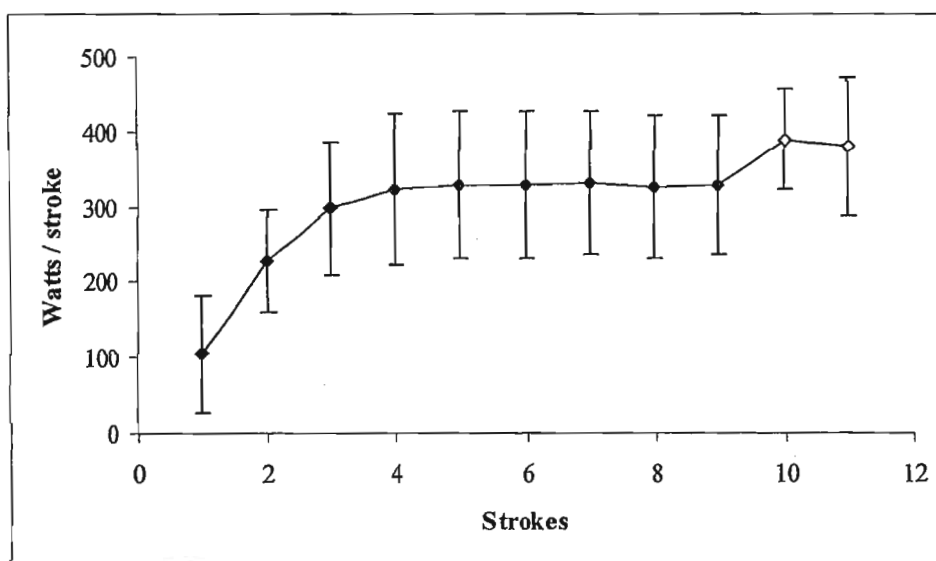


Figure 3. The average power per stroke (and one standard deviation), during the 10 second maximal test.

When the peak power was used to calculate the increments for the VO_2max test, 3 subjects had increments of 10 W, 7 subjects had increments of 15 W and 3 required 20 W increases.

4.2 VO_2max tests

The results of the different parameters measured during the VO_2max tests on the kayak ergometer and the treadmill are shown in Table 2.

Table 2: Respiratory parameters during kayak ergometer and treadmill testing. Data are presented as the mean and one standard deviation of the metabolic equivalent (MET), oxygen consumption (VO_2), carbon dioxide production (VCO_2), respiratory exchange ratio (RER), heart rate (HR), oxygen pulse (O_2 Pulse), exhaled tidal volume (VE), minute ventilation (VT), respiratory rate (BF), oxygen equivalent (EqO_2) and carbon dioxide equivalent (EqCO_2), measured at peak VO_2 . Statistical analysis was by paired t test.

	KAYAK	TREADMILL	P =
MET	12.0 ± 2.4	15.1 ± 1.7	0.0002
VO_2 (ml/min)	3511 ± 691	4443 ± 726	0.0005
VO_2 (ml/min/kg)	41.9 ± 8.3	52.7 ± 5.5	0.0003
VCO_2 (ml/min)	3929 ± 802	5253 ± 905	0.0003
RER	1.12 ± 0.06	1.18 ± 0.05	0.0054
HR (b/min)	172.1 ± 8.7	177.8 ± 7.1	0.0036
O_2 PULSE (ml/b)	20.4 ± 3.9	25.0 ± 4.1	0.001
VE (l/min)	116.9 ± 19.7	141.2 ± 21.5	0.0005
VT (l)	2.546 ± 0.718	3.062 ± 0.457	0.054
BF (b/min)	48.2 ± 13.5	46.3 ± 5.5	0.4240
EqO_2 (l/l)	33.0 ± 3.9	31.4 ± 3.1	0.1
EqCO_2 (l/l)	29.5 ± 3.1	26.6 ± 2.4	0.003

Two subjects did not achieve an RER of 1.1 on the kayak ergometer and may therefore not have reached their maximum oxygen consumption. At peak VO_2 , the metabolic equivalent, oxygen consumption, respiratory exchange ratio, heart rate max and oxygen pulse were all significantly lower on the kayak ergometer than on the treadmill.

Of interest is the maximum heart rate, which was on average 5.8 ± 5.8 b/min lower with arm exercise, with a range of 0 – 18 b/min (figure 4).

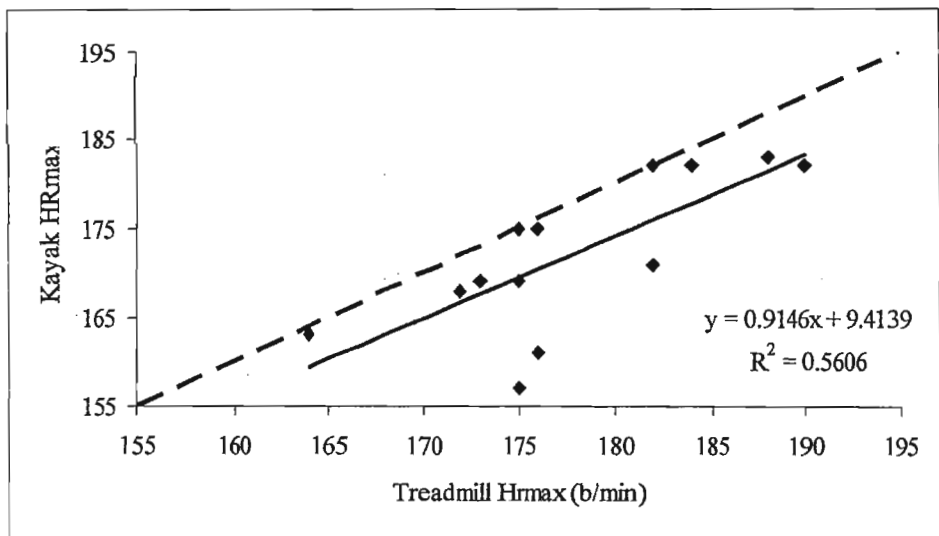


Figure 4. Scattergram of the maximum heart rates achieved on the treadmill and kayak ergometer. The dotted line represents the line of equity, where the heart rates are equal and the solid line represents the regression line. The regression equation is given.

Two subjects achieved the same heart rates with arm and leg exercise. With arm exercise, 8 of the 13 subjects had heart rates within 5 b/min of their treadmill HRmax. Three subjects had a difference in heart rates of 11- 18 b/min. The relationship between the differences in HRmax and $\text{VO}_{2\text{max}}$ is shown in figure 5.

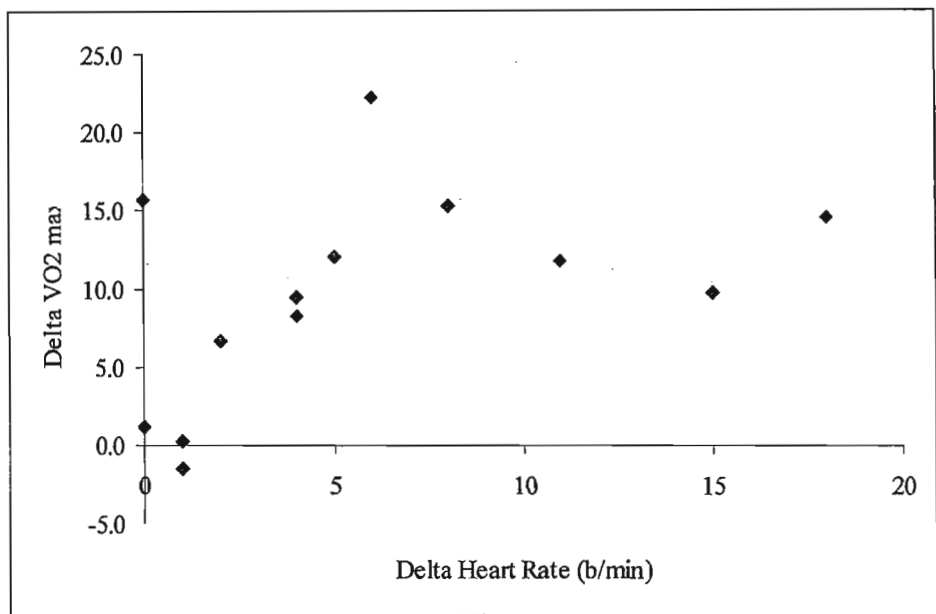


Figure 5. Scattergram of the difference in maximum heart rate and maximum oxygen consumption, expressed in ml/kg/min.

Two subjects achieved the same HRmax with arm and leg exercise but with differences of 1.1 and 15.7 ml/kg/min in their VO₂max respectively.

Of the ventilatory parameters, minute volume was significantly greater on the treadmill ($p < 0.005$). Exhaled tidal volume on the kayak ergometer showed a trend towards being reduced and this approached a significance of $p = 0.054$. At maximal exertion, respiratory rate was not different, and the difference in minute volume is attributable to the reduction in tidal volume.

4.3 Submaximal exercise

4.3.1 Heart rate and oxygen consumption

The relationship between heart rate and oxygen consumption on the treadmill and kayak ergometers is shown in figure 6.

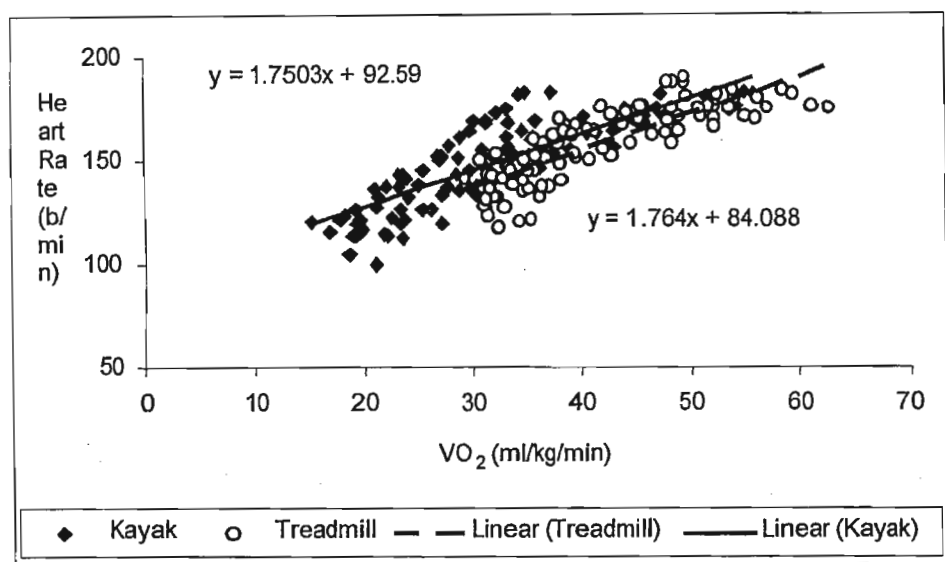


Figure 6. Scattergram of oxygen consumption and heart rate at different exercise intensities on the kayak ergometer and treadmill (the regression equations are shown).

The slopes of the regression equations are similar. At any given oxygen consumption (a measure of exercise intensity), heart rate will be greater with arm exercise. Similarly, at any given heart rate, oxygen consumption will be higher with leg exercise.

Many canoeists are presently using HRmax based on their lower limbs when training for canoeing. To examine the effect of using the leg HRmax when canoeing, the heart rate achieved on the kayak ergometer was divided by the HRmax achieved on the treadmill, to give the upper limb-derived heart rate as a percentage of the lower limb heart rate. The percentage VO₂max achieved on the kayak ergometer and the corrected percentage HRmax based on the leg HRmax was then plotted and compared with the relationship of percentage VO₂max and percentage HRmax on the kayak ergometer (figure 8). The regression lines indicate that when basing canoeing training on a percentage of leg HRmax, a slightly higher percentage of arm VO₂max will be achieved than when heart rate zones are based on arm HRmax.

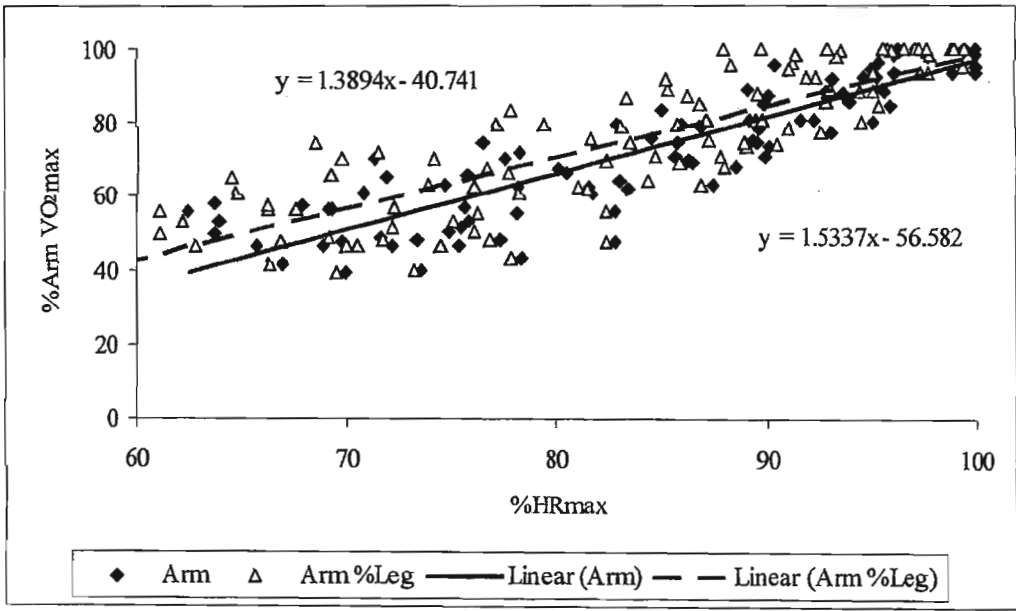


Figure 8. Scattergram of the arm heart rate expressed as percentage of arm HRmax and leg HRmax, and the percentage of arm VO₂max. The regression equations are given.

The regression equations were used to calculate the percentage VO_2max utilised at 60, 70, 80 and 90 % of arm-derived HRmax and leg-derived HRmax. Use of leg-derived HRmax to set training intensities for kayaking would result in the paddler training at a % VO_2max that was 7.2 % higher at 60 % HRmax, 5.7 % at 70 % HRmax, 4.3 % at 80 % HRmax, and 2.8 % at 90 % HRmax.

4.3.2 Respiratory parameters

At maximal exercise, it was noted that with arm exercise, the exhaled tidal volume was reduced and that this approached significance. The respiratory rate showed a trend of being slightly higher, although this was not significant. The relationship of respiratory rate and metabolic equivalents is shown in figure 9.

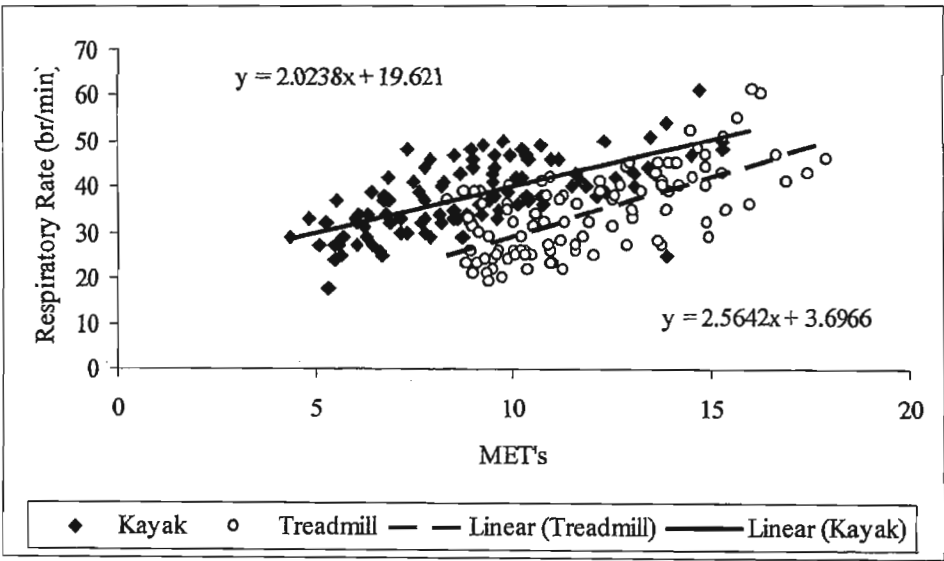


Figure 9. Scattergram of the respiratory rate and metabolic equivalents when exercising on the kayak ergometer and treadmill. The regression equations are shown.

At any given MET (a measure of submaximal exercise intensity), the respiratory rate 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 MET's, respiratory rate would be increased by 5.1 to 13.8 breathes per minute. The difference is significant: $p < 0.0001$, (paired, two tailed students t test). The difference in tidal volume approached significance at maximal exercise. The relationship between tidal volume at different MET's is shown in figure 10.

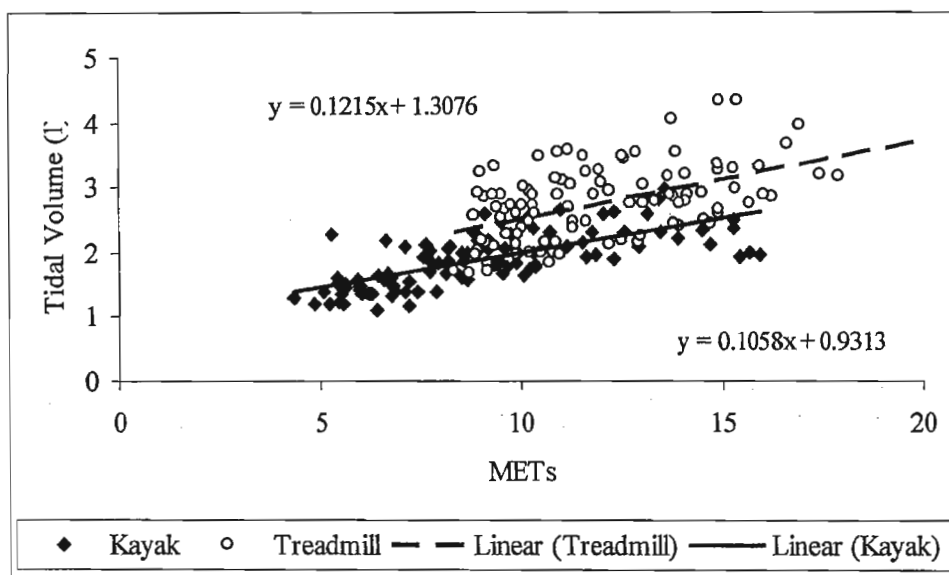


Figure 10. Scattergram of the relationship of tidal volume to MET's on the kayak ergometer and treadmill. The linear regression equations are shown.

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 MET's. Tidal volumes were significantly reduced when kayaking, ranging from a difference of 439 ml at 4 MET's, to a difference of 690 ml at 20 MET's: $p < 0.0001$ (paired, two tailed student's t-test).

The relative effects of a reduced tidal volume and increased respiratory rate during submaximal exercise is examined by investigating the relationship between minute volume and MET's (figure 11).

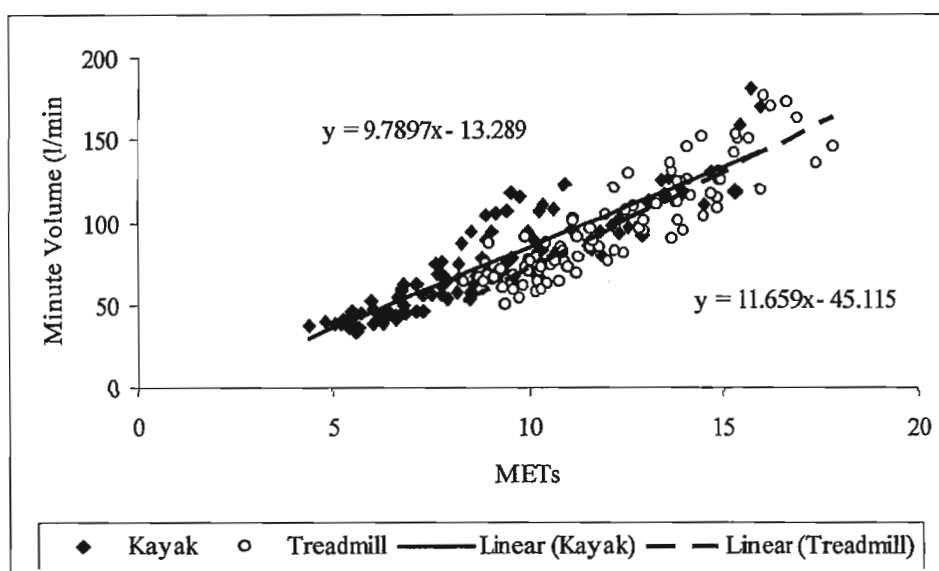


Figure 11. Scattergram of the relationship between minute volume and MET's on the kayak ergometer and the treadmill. The regression equations are shown.

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 metabolic equivalents. The differences in minute volume were statistically significant when limited to the range of MET's achieved on the kayak ergometer: $p = 0.0109$ (paired, two tailed students t-test).

CHAPTER 5

DISCUSSION

Athletes' maximum heart rates have been accepted as being on average ten to thirteen beats per minute lower with upper limb exercise than when lower limb exercise is performed. Also, when comparing upper and lower limb exercise at any given submaximal exercise intensity, heart rate and oxygen consumption have been shown to be higher with upper limb exercise. We tested whether this is valid for canoeists, who would be expected to exhibit comparatively greater upper body strength and anaerobic capacity through paddling training. Indeed, one study of elite canoeists found that their maximum heart rates with upper limb exercise were higher than their lower limb exercise at maximum heart rate (DalMonte and Leonardi, 1976). Our study showed that the median difference in heart rate maximum between upper and lower limb exercise was only 4 beats per minute, which does not agree with the previously stated values. However, at any submaximal workload, the heart rate on the kayak was shown to be about 8 beats per minute higher, which confirmed the observation that heart rate is higher when using the arms.

Furthermore, kayakers use training zones based on their leg heart rate maximum. Some authors have suggested that arm exercise prescription based on maximal heart rate derived from leg testing may be inappropriate (Pimental, *et al*, 1984). The data from this study suggest that for most canoeists, heart rate training zones based on leg HRmax are suitable for kayaking.

The male canoeists tested in this study (n=13) were representative of the paddlers in the Durban area. The sample size was more than in similar studies performed (Tesch, *et al*, 1976; and Pivarnik, *et al*, 1988).

The average age of the canoeists, 33 ± 10.0 years is somewhat older than in comparable studies (Tesch, *et al*, 1976; and Nikolic and Todorovic, 1984). The wide age range (19 - 51 years) of paddlers in this study is not a disadvantage as it allows for a general comparison of the heart rate and oxygen consumption of a broad spectrum of competitive canoeists who would use heart rate monitoring for training.

The ten second maximum test was used to assess the maximum power each athlete could generate over a very short period whilst kayaking. The peak power achieved was used to calculate the increments for the VO_2max test. The mean of 9 strokes indicates that each athlete was able to perform approximately one stroke per second. The power generated reached a plateau by the fourth stroke. The factors involved in limiting this output are beyond the scope of this study. The power appears to increase for the tenth and eleventh strokes but only in 5 subjects – the latter data were therefore skewed.

Maximum heart rate was on average 6 beats per minute lower with upper limb exercise, with some subjects achieving the same or very similar HRmax. There were subjects whose upper limb HRmax was more than $10 \text{ beats} \cdot \text{min}^{-1}$ lower. This raises the question as to whether there is a subset of individuals who are not able to achieve the same or similar heart rates whilst upper limb training. The possibility exists that these subjects did not perform maximally on

the kayak ergometer or that they were at a higher level of running training than canoeing training. This is an area that requires further investigation.

VO₂max on the kayak was lower than on the treadmill. This may be explained on the basis of the utilization of a smaller muscle mass and reduced HRmax. The observation of increased heart rate at submaximal intensities with upper limb exercise may be on the basis of diminished venous return when exercising in the seated position. In kayaking, the leg muscles are used to a far lesser degree than in running and associated with this would be a reduction in venous return from the legs. The seated posture with a forward lean 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. A further effect of this is to reduce diaphragmatic excursion. This would explain the reduction in tidal volume that was noted during upper limb exercise and the significant increase in respiratory rate to compensate and maintain adequate ventilation.

These findings do not confirm the findings made by DalMonte and Leonardi (1976), who found that kayakers were able to reach higher VO₂max values with their arms on kayaks than with their legs on a treadmill. The reason for this may be that DalMonte and Leonardi (1976) tested elite canoeists only, whereas this study tested canoeists across the spectrum, and did not distinguish elite from social paddlers. It may also be that because South African canoeists are adapted to both running (for portaging) and paddling, and not paddling only, the athletes in this study were less well adapted to canoeing than their international counterparts.

Bunc, *et al* (1987) and Bunc and Heller (1991) have shown that the better the athlete is adapted to the specific load, the higher the maximum oxygen consumption.

At submaximum effort - up until the anaerobic threshold is reached, just below an RER of 1 - the heart rates were on average the same for the treadmill and kayak ergometer readings. These findings support the hypothesis as regards the heart rate, but only at submaximum effort. The implications of this are that for canoeists, the heart rates established whilst running may actually be used to help guide training in kayaking. This contradicts what some authors have suggested (Pimental, *et al*, 1984; Franklin, 1989).

When the heart rate maximum for the treadmill and the kayak were plotted against each other, 11 out of the 13 subjects had a lower HRmax on the kayak. Importantly, 10 of the 13 athletes had a heart rate difference that was less than 10 beats per minute and the median difference was 4 beats per minute. This is approximately one third of what has generally been accepted when comparing upper and lower limb exercise for the adult athletic population.

Of the two subjects who achieved the same HRmax for upper and lower limb exercise, one of them had a difference in VO_2max of $15.7 \text{ ml.kg}^{-1}.\text{min}^{-1}$ between his arm and leg exercise. This was similar to the VO_2max difference noted in the three subjects whose arm HRmax was $11 - 18 \text{ b.min}^{-1}$ lower than their leg HRmax. As HR and VO_2 are generally comparable at any exercise intensity, this finding may suggest that the athlete with a reduction in VO_2max noted at the same HRmax may have been cardiovascularly fit for lower limb exercise but not upperlimb exercise at the time of testing.

Although the response of heart rate and oxygen consumption to kayaking and running is similar at any given workload, the heart rate on the kayak is about 8 beats per minute higher, confirming the observation that at any submaximal workload, heart rate is higher when using the arms. Similarly, at any given heart rate, oxygen consumption is lower with arm exercise. Use of the linear regression equations also confirm the observation that heart rate is higher when using the arms (Sleamaker, 1989; Miles, *et al*, 1989; McArdle, *et al*, 1996).

Plotting the percentage heart rate max with the arms against the percentage VO_2max of the arms, and percentage HRmax with the legs against the % VO_2max of the legs, the heart rate - VO_2max relationship was found to be similar for arm and leg exercise. Mimicking the situation of using the leg heart rate max to determine the training zones, it was found that based on the leg HRmax, a slightly higher percentage of arm VO_2max is achieved at any given percentage heart rate, which is practically negligible. Some authors have suggested that arm exercise prescription based on maximal heart rate derived from leg testing may be inappropriate (Pimental, *et al*, 1984; Franklin 1989). Yet, this was not confirmed by our study, and it is suggested that heart rate training zones based on leg HRmax are indeed suitable for kayaking.

When analysing the relationship of respiratory rate and metabolic equivalents (MET; a measure of submaximal exercise intensity), it appears that at any given MET, there is a lower respiratory rate on the treadmill than on the kayak. Likewise, at any given respiratory rate, the metabolic equivalent is lower on the kayak. This might suggest that the athletes were

fitter for treadmill running, but as already discussed, the athletes took smaller breaths on the kayak, which caused an increased respiratory rate.

At any metabolic equivalent, the tidal volume was lower on the kayak ergometer than on the treadmill. Similarly, at any tidal volume, the metabolic equivalent was lower on the kayak ergometer. This might suggest that the athletes were less efficient on the treadmill, as they were requiring to breathe more air whilst performing at the same exercise intensity. Indeed, the difference in tidal volume approaching significance at maximal exercise may support this, although one cannot exclude the importance of restricted postures accounting for reduced air consumption whilst kayaking (Cunningham, *et al*, 1975).

The minute volume on the kayak ergometer was higher than on the treadmill, for all but the highest intensities of exercise. This reinforces the previous two respiratory parameter findings of lower tidal volume and higher respiratory rate on the kayak, because the athletes therefore required more air consumption per minute in order to compensate for the previous two findings.

A few subjects said that the kayak ergometer appeared to have presented a 'different' resistance to that experienced in water, and that different muscles appeared to be utilised. This anecdotal finding does not support the findings of van Someren, *et al* (2000), who found that the K1 Ergo accurately simulates the short-term, high intensity demands of kayaking. Furthermore, blood lactate concentrations have also been shown to be similar during kayak ergometer and open water kayaking (van Someren and Oliver, 2002). Nevertheless, this

phenomenon may have resulted in premature fatigue in some canoeists in this study. Some authors have stated that skeletal muscle blood flow (as well as peripheral adaptations in trained muscles) appear to limit VO_2max in arm and leg exercise (Reybrouck, *et al*, 1975 and Bhambhani, *et al*, 1991). Although fatigue was not studied in this research, these comments from some of the kayakers tested in our study, raise the question as to whether the kayakers were fatiguing due to cardiovascular incapacity or muscle fatigue. This remains a largely unsolved question to date.

5.1 Conclusions

The purpose of this investigation was to examine the heart rate and oxygen consumption relationship in regular canoeists of varying ability, to determine whether separate upper limb specific heart rate training zones are required for canoeing.

Based on the results of this study, kayakers who train regularly, appear to be able to attain similar maximum heart rates with upper and lower limb exercise, but a lower VO_2max when exercising with their arms. The heart rate oxygen consumption response is the same for upper and lower body exercise; and the issues regarding a reduced HRmax and increased heart rate at any submaximal workload do not appear to apply to canoeists. It is therefore concluded that heart rate training zones based on leg HRmax are suitable for kayak training.

5.2 Study limitations

The rather small sample size.

No distinction was made between endurance and sprint canoeists accepted onto the study.

There was no distinction made between elite and social canoeists.

Individuals with certain chronic conditions (i.e: greater than three months duration) were not excluded from the study (one athlete suffered with chronic sinusitis and three with chronic asthma). This may have compromised their power outputs.

Not all athletes were at their peak physical fitness, as admitted by some. This may have skewed some of the results.

Some athletes reported feeling claustrophobic in the facemask of the Oxycon whilst canoeing and running. This may have adversely affected their performances.

As with any study involving human subjects, it is important to acknowledge the Hawthorne effect i.e: that individuals may inadvertently alter their performance knowing that they are being monitored.

One of the unforeseeable negative consequences of testing athletes back-to-back (one after each other) is that they consistently compared their results with one another, or with

colleagues whom they knew to be stronger. This may or may not have had a negative (or positive) psychological influence on their performance(s).

5.3 Suggested future research / recommendations

It is suggested that greater numbers of canoeists be tested in future studies, in order to allow for greater extrapolation of data.

Further work is required to establish if there is a gender difference.

Based on the three subjects who had a difference in arm and leg HRmax of more than 10 beats per minute, it needs to be determined whether there is a subset of paddlers who cannot get their arm heart rate maximum to approximate that of their legs.

Distinguish between elite and social athletes, as, according to Pendergast, *et al* (1989), the energy cost to paddle a given distance is lower for elite male paddlers than for the unskilled, which would obviously impact on performance.

As was found in this study and others (Pendergast, *et al*, 1989) - that significant differences between both females and males as regards energy costs for paddling do exist, and that observed differences between men and women during arm exercise have been attributed to the size of the contracting muscle mass and not sex-related differences in oxygen delivery or

utilization (Washburn and Seals, 1983), future studies should ensure the testing of either one of the two groups, and not use both sexes in the same study.

Distinguish between endurance and sprint canoeists, or test both groups separately.

To use the easily obtainable cross-sectional area of the muscles plus bone of the upper arm to standardize the VO_2 peak of arm cranking, as suggested by Enders, *et al* (1994).

Finally, to test the athletes' blood lactate levels, in order to compare findings with respect to anaerobic threshold.

APPENDICES

APPENDIX A

THE GAS ANALYSER CALIBRATION

Introduction

A metabolic instrument requires regular calibration in order to ensure optimal functioning and reliable test results. For that reason, the Oxycon is provided with complete computer controlled calibration facilities.

Calibration was performed with analysers sufficiently warmed-up and at regular intervals. The system was switched on 1 hour before starting a calibration. The gas calibration was performed before every exercise test. The volume calibration was performed once a day before the first test or after having the volume sensor exchanged.

Temperature and barometric pressure are important parameters in the calculation of the variables measured by the Oxycon. These data were automatically and constantly measured by the Oxycon

Selecting the Calibration Mode

On the computer, from the Main Group window, the "Calibration" group was selected.

The Calibration Group window was shown. The icon with the syringe was clicked to perform a volume sensor calibration and the "Gas Analyser Calibration" icon was clicked to perform a gas analyser calibration.

Gas Analyser Calibration

To perform a gas analyser calibration with the Oxycon, the calibration gas bottle was connected to the Oxycon with the click-on fittings. The gas supply on the bottle was opened. The recommended calibration gas composition is 5-6% CO₂ in Nitrogen. The pressure of the gas was between 1.5 and 2.0 bar. The Gas Analyser Calibration icon was then double-clicked. The Gas calibration screen was shown.

Settings in the menu bar were clicked and the calibration gas concentrations edited, if required, e.g. if a new calibration gas bottle was connected with an alternative calibrations gas content.

The (OK) command button was clicked and the calibration commenced with clicking the first icon.

Firstly, the transport time for the gas through the Twin Tube was established: eight boluses of calibration gas were fed to the analysers from the Twin Tube connector. Then, ambient air was fed to the analysers after which the actual gas calibration was performed. After approximately two minutes, the gas analyser calibration was finished and the old and new data for gain and offset displayed in the box on the right side of the screen.

The “Exit” icon was clicked and the questions answered: settings were then saved (if the calibration gas contents were changed) and Save Calibration was clicked to save the new Gain and Offset factors. The screen then switched to the Calibration group window.

Flow-Volume Sensor Calibration

For calibration of the flow-volume sensor, a calibration syringe with a volume between 0.05 and 5 litres is required; 2 or 3 litres is recommended.

To start the Volume calibration, the Volume Calibration icon was clicked.

The volume calibration screen was shown. To change settings like calibration syringe volume, the number of strokes over which the calibration is to be performed, and the type of display and scaling during the calibration, the Settings selection item in the menu bar was made.

The Setting box was shown; after editing, clicked (OK).

To start the actual calibration, the first icon was clicked and the pumping started.

Depending on the settings in the Setting screen, a screen with bars indicating the volume of the pump or flow-volume loops were shown.

The number of strokes displayed on the screen were then performed, after which the calibration stopped automatically. The new data was shown in the box on the right side.

If the data was acceptable, the bottom icon was clicked. The screen then switched to the Calibration group window.

APPENDIX B
COMPUTER RANDOMIZATION RESULTS

Number of groups: 2
Number of subjects in each group: 8
Group 1: Kayak
Group 2: Treadmill

Subject Number	Group	Activity
1	1	K
2	1	K
3	2	T
4	1	K
5	1	K
6	2	T
7	2	T
8	1	K
9	1	K
10	1	K
11	1	K
12	1	K
13	1	K
14	2	T
15	2	T
16	1	K

APPENDIX C

ATHLETE INFORMATION SHEET

As you know, many people now use their heart rate to gauge the intensity of their training sessions. Several canoeists have noticed that the target heart rate zones used for running training do not feel right for canoeing training. This may be because the arm muscles are smaller than the leg muscles and the relationship between heart rate and oxygen use by the working muscles may be different in canoeing and running. If this is so, the heart rate training zones may differ.

This research study is attempting to establish whether upper limb exercise results in a lower heart rate and oxygen consumption than lower limb exercise and if there is a difference, is it the same in canoeists who regularly train their upper limbs and runners who don't train their upper limbs. We hope that the information gained will enable us to provide heart rate training zones, based on upper limb exercise, for canoeists in particular. You will be required to participate in both upper limb, or lower limb exercise and have an equal chance of performing upper limb exercise first, and then lower limb, or vice-versa. You will be randomly selected to perform either the kayaking, or the treadmill first. The lower limb exercise will involve running on a treadmill with the speed and gradient increasing every minute, after a 5 minute warm up period at 8 km per hour. The upper limb exercise involves paddling on a kayak ergometer at increasing workloads every minute, after a 3 minute warm-up at between 30-40 watts.

A heart rate monitor belt will be placed around your chest and a facemask placed over your nose and mouth. The mask allows you to breathe in air and takes the air that you breathe out, into a computerized apparatus to calculate how much oxygen you are using during exercise. You shall then be required to run or paddle for approximately fifteen minutes, at increasing intensity, until maximum effort and exhaustion. Two to three days later, you will then need to return to perform the other exercise and the procedure above will be repeated. Your responsibilities include: that you not have exercised at least one day prior to either of the two testing sessions; that you keep to the agreed appointment times (in order to be tested at almost exactly the same time on each of the testing days); that you inform me of any recent (past 72 hours) injuries to your upper or lower limbs; that you not have taken any current heart rate altering medication (eg: beta blockers), for whatsoever reason, and that you not have eaten 3 hours prior to being tested. You may, as a result of the intensity of the exercise, experience some muscle soreness up to three days following the exercise. As you may well know, this is normal following intense exercise and will resolve within a few days thereafter. This exercise should not however, harm you in any way. As with any exercise on a treadmill, there is always a risk of falling and injuring yourself. As you will be exercised to exhaustion, there is also a very small but real risk of having a cardiac event. Medical personnel will be present during testing.

Your participation in this study is entirely voluntary and you may withdraw, or refuse to participate at any time in the study. Should you choose to do this, this action will in no way jeopardize you.

By signing this document, it is accepted that you understand that the technician, supervisor(s), researcher, statistician, the ethics committee, and the relevant authorities,

may have direct access to your records. However, this shall in no way violate your confidentiality. Should this study be published, your identity shall remain confidential.

Professor Maurice Mars, Department of Physiology, is the person to contact should you require any further information on this study, or should you be injured during the study. I, the researcher, will contact a member of the ethics committee in the event of an injury to you.

Should you fail to meet the necessary responsibilities, as previously noted, your participation in this study will need to be terminated. You will be required to participate for no longer than two half hour sessions over approximately a one week period. There will be fifteen subjects participating in this study. Should you wish, you will be advised of your optimal target training heart rate zones for canoeing and or running training.

NEIL GOMES

APPENDIX D
INFORMED CONSENT FORM

A comparison of upper and lower limb exercise in canoeists using the heart rate and oxygen consumption relationship.

G.6.1 I, (Name) hereby consent to the following procedure and/or treatment being conducted on myself or the person indicated in H.5.4 below:

G.6.2 I acknowledge that I have been informed by:

(Name) concerning the possible advantages and possible adverse effects which may result from the abovementioned procedure and/or treatment, and of the ways in which it is different from the conventional procedure and/or treatment.

I, (Name) hereby acknowledge that I understand and accept that this study involves research and the “Information to Patients” leaflet has been handed to me in connection with this study.

G.6.3 I agree that the above procedure and/or treatment will be carried out and/or supervised by

NEIL GOMES
NEILL KLEINVELDT
PROFESSOR MAURICE MARS

G.6.4 I acknowledge that I understand the contents of this form, including the information provided in the “Information to Patients” leaflet and as the SUBJECT, freely consent to the above procedure and/or treatment being conducted on: (Name)

G.6.5 I am aware that I may withdraw my consent at any time without prejudice to further care.

Signed: Subject/Partner/Guardian	Date:
Signed: Witness	Date:
Signed: Informant	Date:
Signed: Researcher	Date:

APPENDIX E
ATHLETE HISTORY + TESTING: KAYAK

NAME:SAVED AS:DATE:

MEDICATION:

ILLNESS:

AGE:

HEIGHT:

WEIGHT:

ARM LENGTH:

ARM SPAN:

HAND GRIP:

MAX TEST:

W

@

SECS

INCREMENTS:

W

TIME START:

START

@

40

W

3 MIN

W

4 MIN

W

5 MIN

W

6 MIN

W

7 MIN

W

8 MIN

W

9 MIN

W

10 MIN

W

11 MIN

W

12 MIN

W

TIME END:

ATHLETE HISTORY + TESTING: TREADMILL

NAME: _____ SAVED AS: _____ DATE: _____

MEDICATION: _____

ILLNESS: _____

AGE: _____

HEIGHT: _____

WEIGHT: _____

ARM LENGTH: _____

ARM SPAN: _____

HAND GRIP: _____

MAX TEST: _____ W _____ @ _____ SECS INCREMENTS: W _____

TIME START: _____

TIME (min)	SPEED (km/h)	GRADIENT (degrees)
0-6	8	3
6-7	9	4
7-8	10	5
8-9	11	6
9-10	12	7
10-11	12	8
11-12	12	9
12-13	12	10
13-14	12	11
14-15	12	12
15-16	12	13

TIME END: _____

APPENDIX F

HEART RATE MONITOR PLACEMENT

The POLAR transmitter was attached onto the elastic belt.

The belt strength was adjusted so that the fit was snug, but not too tight.

With the transmitter facing outward, and the POLAR-logo in the right position, the round end of the belt lock was inserted into the buckle to secure the belt around the athlete's chest.

The transmitter was then centred on the athlete's chest, below the pectoral muscles (breasts in the females, performed by the athlete herself).

The transmitter was then pulled away from the chest, stretching the belt and moistening the conductive electrode strips located on both sides. The transmitter was used against the skin, for optimal results.

The POLAR wrist monitor was then placed on the arm as an ordinary watch, by the athlete.

OXYCON MASK ATTACHMENT

The face mask is designed to form an air-tight seal over the patient's nose and mouth. The mask was placed over the patient's face and the two straps were connected to both sides of the mask. One side has permanent connections and the other side uses a hook. There is an adjustable part of the strap to ensure an optimal fit. Alternatively a mouthpiece with nose clips can be used. The nose clip prevents leakage through the nose.

APPENDIX G

COMPUTER PROGRAM

Exercise Test Description

The standard exercise test is made up of six phases, which are displayed in the bottom right corner of the computer screen:

1. Ready
2. Background Zeroing
3. Standby
4. Resting
5. Load
6. Recovery

1. Ready

In the Ready-phase, the Oxycon does not function yet, but is ready to start operation; with the first icon or key 'F1', the Oxycon switches to the next phase.

2. Zeroing

In this phase, the oxygen and the carbon dioxide analyser of the Oxycon are fed with roomair, and the values are used as a reference. The system automatically finishes this phase and switches to the Standby phase.

3. Standby

In this phase, the patient is connected to the Oxycon via the sample line and the electrical cable of the volume sensor. Measured data are shown but will not be saved. One switches to the next phase with the first icon or key 'F1'.

4. Resting

The measured data are saved in computer memory and a workload level is imposed to the patient to warm-up, automatically or by intervening in the computer protocol; this protocol (when activated) also controls the switching to the next phase.

5. Load

The actual workload protocol is started and the predefined workload protocol is imposed to the patient; the next phase is started automatically or manually with the first left icon or key 'F1'.

6. Recovery

The final phase of the exercise test is used to let the patient cool down with a low or decreasing workload; as soon as this phase is finished, the system switches to the Ready status.

Protocol

A workload protocol controls the test procedure if it is activated in the startup menu: it switches the Oxycon fully automatically from the Resting phase via Load and Recovery to Ready, and controls the changes in workload following a strict pre-defined scenario. The

protocol also controls the actions like starting the blood pressure device, starting an ECG and bringing to the operator's attention to perform activities like blood gas analyses etc (where applicable). The protocol can be interrupted by the operator during the test.

To edit the workload protocol during the exercise test, the second icon is clicked; the edit protocol window is shown and the data can be changed.

After acceptance, the Apply button is clicked, the edited protocol is used for the remainder of the test. To close this box, click OK.

When the Recovery phase is finished, the patient stops exercising and can be disconnected from the Oxycon.

The facemask or mouthpiece is *not* removed during the *recovery* phase, as the metabolic parameters during this phase may be important for later analysis of the test.

If the test is stopped prematurely due to incapacity of the patient, a physician should supervise from this point onward.

When the recovery phase is finished, the bottom right icon with door is shown. To finish the test and to save the results, this icon is clicked or 'F10' pressed.

The save measurement box is shown; and the data saved. As soon as the test is saved, the Main Group window is shown.

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