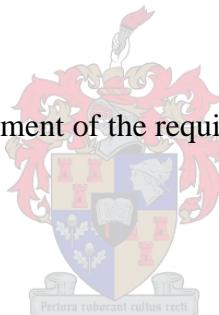


**THE RELATIONSHIP BETWEEN RESPIRATORY MUSCLE  
FATIGUE, CORE STABILITY, KINANTHROPOMETRIC  
ATTRIBUTES AND ENDURANCE PERFORMANCE IN  
COMPETITIVE KAYAKERS**

BY

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Thesis presented in the partial fulfilment of the requirements for the degree of Master of Medical Sciences at Stellenbosch University



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April 2005



## **DECLARATION**

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature: .....

Date: .....

## SUMMARY

The purpose of this study was to determine the physiological and kinanthropometric attributes, respiratory muscle strength, and core stability of successful endurance paddlers, and to investigate the associations of these characteristics with kayak endurance performance in the laboratory and the field.

Twenty male competitive paddlers (age:  $28 \pm SD 7$  years, height:  $184 \pm SD 7$  cm and weight:  $80 \pm SD 7$  kg) were categorised in two ability groups, Elite and Sub-Elite. Testing included kinanthropometric measurements, maximum aerobic capacity, pulmonary function, six core stability tests, a 30 min endurance performance test (EPT) on the K1 Ergo and a 10 km time trial (TT) on the water. Maximum inspiratory mouth pressure (MIP) was measured before and after the 30 min EPT on the K1 Ergo to assess respiratory muscle fatigue.

The Elite paddlers demonstrated significantly greater values for sitting height (as a percentage of stature), relative  $VO_{2\max}$ , PPO, PPO/kg, MVV and MIP compared to the Sub-Elite paddlers (All  $P < 0.05$ ). They also demonstrated a significantly greater average PO and average back stroke length during the 30 min K1 Ergo EPT ( $P < 0.05$ ) and a significantly faster race time ( $44:10 \pm 1:17$  vs  $47:34 \pm 3:14$  min:s) during the 10 km water TT ( $P < 0.05$ ), compared to the Sub-Elite paddlers. The paddlers did not experience respiratory muscle fatigue (as determined by change in MIP) after the 30 min K1 Ergo EPT. Significant intraclass correlations coefficients of  $r = 0.81$  for average PO (30 min K1 Ergo EPT),  $r = 0.76$  for MIP, and  $r = 0.95$  for 10 km performance time, revealed the high repeatability of these tests. Significant relationships were found between the two endurance performance tests (30 min K1 Ergo EPT and 10 km water TT,  $r = -0.64$ ,  $P < 0.05$ ) and between both tests and a number of kinanthropometric, physiological and respiratory muscle function parameters. Stepwise multiple regression analysis revealed that PPO and MVV predicted endurance performance (average PO) on the K1 Ergo ( $R^2 = 0.75$ , SEE = 15 W), whereas relative  $VO_{2\max}$  and best MIP predicted 10 km performance time on the water ( $R^2 = 0.64$ , SEE = 115 s).

The results of this study suggest that superior maximum aerobic capacities and respiratory muscle function distinguish successful paddlers from less successful paddlers and may be used to predict kayak endurance performance in the laboratory as well as on the water. No respiratory muscle fatigue occurred during the 30 min K1 Ergo EPT, indicating that respiratory muscle fatigue may not be a limiting factor to 30 min kayak endurance performance. The core stability results demonstrated no relevance to kayak endurance performance.

## OPSOMMING

Die doel van die studie was om die fisiologiese en kinantropometriese eienskappe, respiratoriese spiersterkte, en rompspier stabiliteit van suksesvolle uithouvermoë kajakers te bepaal, asook om die verwantskappe van hierdie eienskappe met kajak uithouvermoë prestasie, in die laboratorium en op die water, te ondersoek.

Twintig kompeterende manlike kajakers (ouderdom:  $28 \pm SD 7$  jaar, lengte:  $184 \pm SD 7$  cm en gewig:  $80 \pm SD 7$  kg) is in 2 groepe verdeel, naamlik Elite en Sub-Elite. Toetsing het die volgende ingesluit: Kinantropometriese metings, maksimum aërobiese kapasiteit, longfunksie toetse, ses rompspier stabiliteitstoetse, ‘n 30 min uithouvermoë toets op die K1 Ergo (30 min K1 Ergo EPT) en ‘n 10 km tydtoets (TT) op die water. Maksimale inspiratoriese monddruk (MIP) is voor en na die 30 min EPT op die K1 Ergo gemeet om respiratoriese spiervermoeienis vas te stel.

Die Elite kajakers het beduidende hoër waardes vir sithoogte (as ‘n persentasie van liggaamslengte), relatiewe  $VO_{2\text{maks}}$ , PPO, PPO/kg, MVV en MIP getoon in vergelyking met die Sub-Elite kajakers ( $P < 0.05$ ). In vergelyking met die Sub-Elite kajakers het die Elite kajakers beduidende beter waardes getoon, m.b.t. gemiddelde kraguitset (PO) en gemiddelde terugslag lengte gedurende die 30 min K1 Ergo EPT ( $P < 0.05$ ) en ‘n beduidende vinniger roeityd ( $44:10 \pm 1:17$  vs  $47:34 \pm 3:14$  min:s) gedurende die 10 km water TT ( $P < 0.05$ ). Die kajakers het nie enige respiratoriese spiervermoeienis (bepaal deur ‘n beduidende verskil in MIP waardes) ondervind na die 30 min K1 Ergo EPT nie. Beduidende intraklas korrelasie koëffisiënte van  $r = 0.81$  vir gemiddelde PO (30 min K1 Ergo EPT),  $r = 0.76$  vir MIP en  $r = 0.95$  vir 10 km prestasietyd, het die hoë herhaalbaarheid van hierdie toetse bevestig. Beduidende verwantskappe is gevind tussen die twee uithouvermoë prestasie toetse (30 min K1 Ergo EPT en 10 km water TT,  $r = -0.64$ ,  $P < 0.05$ ) en tussen beide prestasie toetse en verskeie kinantropometriese, fisiologiese and respiratoriese funksie parameters. Stapsgewyse veelvuldige regressie analises het getoon dat PPO en MVV die prestasie (gemiddelde PO) op die K1 Ergo voorspel ( $R^2 = 0.75$ , SEE = 15 W), terwyl relatiewe  $VO_{2\text{maks}}$  en die beste MIP waarde die 10 km prestasie tyd op die water voorspel het ( $R^2 = 0.64$ , SEE = 115 s).

Die resultate van hierdie studie toon dat beter maksimale aërobiese kapasiteite en respiratoriese spierfunksies meer suksesvolle kajakers onderskei van minder suksesvolle kajakers. Hierdie toetse kan ook gebruik word om kajak uithouvermoë prestasie in die laboratorium, sowel as op die water te voorspel. Geen respiratoriese spiervermoeienis het gedurende die 30 min K1 Ergo EPT voorgekom nie, wat daarop dui dat respiratoriese spiervermoeenis moontlik nie ‘n beperkende faktor vir kajak uithouvermoë prestasie (30 min) in die laboratorium is nie. Die resultate van die rompspier stabiliteitstoetse het geen verwantskap met kajak uithouvermoë prestasie getoon nie.

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## LIST OF ABBREVIATIONS

BD	:	body density (g.cc <sup>-1</sup> )
bpm	:	beats per minute
cmH <sub>2</sub> O	:	centimetres water
CO <sub>2</sub>	:	carbon dioxide
CV	:	coefficient of variation
EMG	:	electromyographic
f <sub>bmax</sub>	:	maximum breathing frequency (breaths.min <sup>-1</sup> )
FEV <sub>1</sub>	:	forced expiratory volume in 1 second (L)
FVC	:	forced vital capacity (L)
h	:	hour(s)
HR <sub>max</sub>	:	maximum heart rate (bpm)
Hz	:	hertz
ICC	:	intraclass correlation coefficient
kg	:	kilogram(s)
kg.min <sup>-1</sup>	:	kilogram per minute
kJ	:	kilojoule(s)
km	:	kilometre(s)
km.h <sup>-1</sup>	:	kilometres per hour
L.min <sup>-1</sup>	:	litres per minute
m	:	metre
MEP	:	maximum expiratory pressure (mmH <sub>2</sub> O, cmH <sub>2</sub> O)
g.cc <sup>-1</sup>	:	grams per cubic centimetre
La	:	lactate
[La]	:	lactate concentration
min	:	minute(s)
MIP	:	maximum inspiratory mouth pressure (mmH <sub>2</sub> O, cmH <sub>2</sub> O)
ml.min <sup>-1</sup>	:	millilitres per minute
mm	:	millimetre(s)
mmH <sub>2</sub> O	:	millimetres water

mmHg	:	millimetres mercury
mmol.L <sup>-1</sup>	:	millimole per litre
MVV	:	maximum voluntary ventilation (L.min <sup>-1</sup> )
N <sub>2</sub>	:	nitrogen
O <sub>2</sub>	:	oxygen
OBLA	:	onset of blood lactate accumulation
P	:	probability value
Pdi	:	transdiaphragmatic pressure
PEF(R)	:	peak expiratory flow rate (L.sec <sup>-1</sup> )
PPO	:	peak power output (W)
PTV	:	peak treadmill velocity (km.h <sup>-1</sup> )
r	:	correlation coefficient
R	:	multiple correlation coefficient
s	:	second(s)
SEE	:	standard error of the estimate
SEM	:	standard error of the mean
TLC	:	total lung capacity (L)
VC	:	vital capacity
VCO <sub>2</sub>	:	volume of carbon dioxide
VE	:	minute ventilation (L.min <sup>-1</sup> )
VEmax	:	maximum minute ventilation (L.min <sup>-1</sup> )
VO <sub>2</sub>	:	volume of oxygen consumption
VO <sub>2max</sub>	:	maximum oxygen consumption (L.min <sup>-1</sup> , ml.kg <sup>-1</sup> .min <sup>-1</sup> )
W	:	Watt
W.kg <sup>-1</sup>	:	Watt per kilogram

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# **CHAPTER ONE**

## **INTRODUCTION**

Flatwater kayaking is contested over distances of 200 m, 500 m, 1000 m, 10 000 m and 42 km. Only the 500 and 1000 m distances are currently recognized as Olympic events, while all 5 distances form part of the World Championships and the international racing programme.

Peak performance during these events requires a mixture of kinanthropometric, physiological, biomechanical and psychological attributes. Scientific testing can identify attributes within these categories that should be able to determine training status and predict performance. These attributes could then be used to assess if specific training would improve performance and also to refine future scientific assessment. These attributes and their level of development will not only vary between different sports, but also between different events within the sport (Fry & Morton, 1991).

In kayaking the upper body of the paddler, together with the paddle becomes a leverage system to overcome the resistance of the water so that the paddler and the boat can move in a forward direction. Generally, it can be hypothesized that the paddler with greater lengths of the extremities and greater body height will form a stronger leverage system and will have a biomechanical advantage over others to succeed in the sport of kayaking. Although a larger individual (with longer extremities and sitting height) will consequently be heavier, this should not limit kayak performance, since kayaking is a non-weight bearing sport. Therefore, kinanthropometry should prove to play an important role in the scientific approach to kayaking.

Currently, research on core muscle stability has primarily used a clinical approach related to the prevention and rehabilitation of lower back injuries. Most researchers investigated the use of different stabilizing exercises in the prevention and rehabilitation of lower back injuries (Moffroid et al., 1993; Axler & McGill, 1997; Rasmussen-Barr et al., 2003), while others investigated the activation of different trunk muscles during various trunk and limb movements or loading tasks in healthy individuals and patients with lower back pain (Zetterberg et al., 1987; Cholewicki et al., 1997; Hodges, 1999).

Although coaches and fitness experts claim that core stability plays an essential role in athletic performance and that core stability training will improve performance in all sports, objective research is greatly lacking. Whether there is a relationship between core stability and athletic performance, and whether core stability training can alter performance, have not been investigated before.

Historically, it was believed that the respiratory system is capable of meeting the demands for ventilation and gas exchange imposed by exercise. Researchers believed that the respiratory system is actually “over-built” compared to the rest of the oxygen transport system. However, in recent years respiratory muscle (RM) fatigue has been observed after short-term maximal exercise (Bye et al., 1984; Bender & Martin, 1985; McConnell et al., 1997) and prolonged submaximal exercise (Loke et al., 1982; Ker & Schultz, 1996), and it was therefore suggested that the respiratory system may be a limiting factor during exercise. Whether RM fatigue affects performance is still a controversial issue, since the various studies investigating this phenomenon resulted in contradictory outcomes.

Furthermore, the majority of studies investigated RM fatigue during leg exercise. Very little research has been done on respiratory muscle fatigue during predominantly upper body exercise modes. It has been suggested that additional demands are placed on the respiratory muscles during arm exercise, since the respiratory muscles also have to stabilize the thorax during arm movements (Volianitis et al., 2001). Thus, it can be hypothesized that the role of RM function on performance may be of greater significance to sports involving predominantly arm exercise, e.g. rowing and kayaking, compared to other sports.

Numerous studies have identified the physiological factors that are essential for successful performance in sport such as cycling and running, but very little research has been conducted on kayaking in general, let alone the various disciplines of kayaking. The existence of only a few previous studies on kayaking can, amongst others, be attributed to the absence of sophisticated laboratory equipment, which specifically simulates the paddling action. Most studies have used an arm crank ergometer or a modified bicycle ergometer to assess paddlers, however, this particular circular movement does not closely mimic the paddling action. The development of an air-braked kayak ergometer affords sport scientists with many opportunities to conduct kayak-specific research.

This study is an attempt to identify the determinants of kayak endurance performance and therefore contribute to the limited knowledge base on flatwater kayaking.

## **CHAPTER TWO**

### **KINANTHROPOMETRY**

#### **A. INTRODUCTION**

The term “kinanthropometry” is derived from three Greek words which mean “to move”, “human”, and “to measure”, respectively (Reilly, 1989). In 1978, Dr. W.D. Ross and his colleagues from the Simon Fraser University (Canada), were the first researchers to fully define kinanthropometry as the “application of measurement to the study of human size, shape, proportion, composition, maturation and gross function. Its purpose is to help us understand human movement in the context of growth, exercise, performance and nutrition.”

(Ross et al., 1980)

The International Society for the Advancement of Kinanthropometry (ISAK), the worldwide recognized body for standardized kinanthropometry, sees kinanthropometry as the interface between anatomy and movement. It is the application of a series of human body measurements (determined directly or through calculations) to produce estimations of body composition and to describe physique. Although anthropometry can be summarized as the scientific specialization dealing with the measurement of humans in a variety of morphological perspectives (body size, shape, composition, proportion and maturation), kinanthropometry is its application to movement, and the morphological factors that influence movement (Reilly, 1989).

Kinanthropometry is a scientific tool which is applied to medicine (e.g. obesity research, forensics, pediatrics), sport science, physical education, human biology and physical anthropology (Reilly, 1989). In sport science, kinanthropometry is specifically used as a scientific tool to understand and/or predict human performance in sports.

#### **B. SPECIFIC TECHNIQUES IN KINANTHROPOMETRY**

The study of physique can basically be divided in two divisions. The first is the measurement of body dimensions and the second is the calculation or estimation of body type and body composition.

## **1. The measurement of body dimensions**

Body dimensions include all direct measurements made on the body through standardized methods. Beunen & Borms (1990) identified the following components of body dimensions:

Skeletal size: This includes measurements of the size of the trunk and limbs such as body height, sitting height, limb lengths, shoulder width and hip width. It also includes calculation of ratios between different size measurements such as sitting height/body height or limb length/trunk size.

Skeletal width of the extremities: This includes the measurement of the width of the extremity bones, such as biepicondylar humerus width and femur width.

Fat component: This component is the direct measurement of subcutaneous adipose tissue thickness at specific sites on the trunk and limbs. The 9 specific sites are: biceps, triceps, subscapular, chest, mid-axilla, iliac-crest, supra-iliac, mid thigh and mid-calf.

Muscle component: This is the measurement of limb and trunk girths, corrected for subcutaneous adipose tissue thickness. This component is used only if body composition is not estimated through mathematical methods.

## **2. Estimation of body type and body composition**

### **2.1 Body Type (Somatype)**

Body typology (somatotyping) is an attempt to place individuals in certain categories, based on their external somatic appearance. Somatype is determined by the interaction of three components, namely, endomorphy, mesomorphy and ectomorphy (Beunen & Borms, 1990). Endomorphy is a body build characterized by the predominance of soft roundness throughout the body, with large digestive viscera and accumulations of fat, a large trunk and thighs, and tapering extremities. Mesomorphy is a body build characterized by the predominance of muscle, bone and connective tissue, with a heavy, muscular physique of rectangular outline. Ectomorphy is a body build characterized by the predominance of linearity and fragility, with a large surface area, thin muscles and subcutaneous tissue, and slightly developed digestive viscera. (Dorland's Illustrated Medical Dictionary, 1985).

Originally, individuals attained a score (on a seven point scale) for each of the three components of somatotype by subjective observation. This technique received much criticism until Parnell (1958) and Heath & Carter (1967) proposed important modifications to this method. In both modified techniques, the three components of body type are determined by means of anthropometric measurements. Ten anthropometric dimensions are needed to calculate the anthropometric somatotype according to the Heath-Carter method. These measurements are body height, body mass, four skinfold measurements (triceps, subscapular, supra-iliac, medial calf), two bone widths (bipicondylar humerus and femur) and two limb girths (arm flexed and tensed calf) (Carter, 2002). Different equations are used to determine the three different components of somatotype (endomorphy, mesomorphy, ectomorphy).

The calculation of the Heath-Carter anthropometric somatotype is an objective procedure, although the validity of the rating depends on the reliability of the direct measurements made on the body. Carter (2002) suggested that the means of two independent measures on the same subjects should not differ significantly, and the Pearson product-moment correlation coefficient should be above 0.90 for test-retest values to be accepted as reliable.

## 2.2 Body composition

Body composition can be studied in many different ways, although the most exact and direct analysis of body composition can only be carried out on cadavers. Most procedures for the determination of body composition are indirect methods based on a two compartment model, where total body mass is divided into a lean body mass component and a fat mass component (Beunen & Borms, 1990).

The measurement of body composition consists of the estimation of body density followed by the estimation of body fat content. Although various equations have been derived for the relation between body fat and body density, the most popular regression equation used to convert body density to percentage body fat is that of Siri (1961):

$$\%BF = 495/BD - 450 \dots \dots \dots \text{eq. 2.1,}$$

where F is the body fat percentage and BD is the body density. This equation assumes that the density of fat is  $0.9 \text{ g.cc}^{-1}$  and the density of fat-free body mass is  $1.1 \text{ g.cc}^{-1}$  (Lohman, 1981). Thus, before the calculation of body fat, body density needs to be determined.

Several methods are available for measuring body density. The most accurate indirect estimation of body density is the method of hydrostatic or under water weighing. Although the method of under water weighing is recognized as the “gold standard” for determining body composition, it is time consuming and it requires expensive equipment as well as considerable tester expertise (Withers et al., 1987). Therefore, the use of anthropometric techniques i.e. skinfold measurements have become quick and inexpensive methods to estimate body composition.

In various populations ranging from athletic to sedentary and from children to the aged, well over 100 equations for estimating body composition, using skinfolds alone or skinfolds and other anthropometric dimensions have been developed in the last 45 years. Most studies yielded population-specific results rather than results highly predictive of body composition across various age groups and types of population. It has been demonstrated that the use of multiple regression equations for estimating body density and subsequently body fat percentage is population specific (Durnin & Womersley, 1974; Smith & Mansfield, 1984). Therefore, care must be taken in choosing the most applicable regression equation based on the specific population involved, for the determination of body composition.

Two sport specific equations have been developed for athletes in general. Forsyth & Sinning (1973) developed an equation based on 50 college students from four different sport codes:

$$BD = 1.10647 - 0.00162(X_1) - 0.00144(X_2) - 0.00077(X_3) + 0.00071(X_4) \dots \text{eq. 2.2,}$$

$[r = 0.84, \text{ SEE} = 0.006]$

where  $X_1$  = subscapular skinfold,  $X_2$  = abdominal skinfold,  $X_3$  = triceps skinfold,  $X_4$  = mid-axilla skinfold. Withers et al. (1987) developed an equation based on 207 elite male athletes (South Australian representative squads) from 18 different sports:

$$BD = 1.0988 - 0.0004(X_1) \dots \text{eq. 2.3,}$$

$[r = 0.749, \text{ SEE} = 0.0058]$

where  $X_1 = \Sigma$  7 skinfolds (triceps, subscapular, biceps, supraspinale, abdominal, front thigh, medial calf). Since these equations rely on the accurate measurements of different skinfolds, it is important to know if these measurements themselves are reliable and reproducible. Jackson et al. (1988) used generalizability theory to estimate reliability that considered both day-to-day and intertester error for body fat measurements using the sum of seven skinfolds (men,  $n = 24$ ; women,  $n = 44$ ). They reported a generalizability reliability coefficient of  $R = 0.977$  ( $P < 0.001$ ).

In conclusion, unless you use the best proven method and equation for the estimation of body composition, you will be prone to relatively large errors of estimate. Although many valid and reliable methods and equations are available to estimate body composition, there will always be the limitation that the available regression equations are not completely applicable to specific subpopulations.

### C. SIGNIFICANCE OF KINANTHROPOMETRY IN SPORT SCIENCE

In sport, kinanthropometric measurement techniques can be used for different purposes, such as the influence of training on physique and subsequently performance, and the study of physical differences between sport participants (Beunen & Borms, 1990). Therefore, kinanthropometry is applicable to sport science.

*Training, physique and performance:* It is believed that athletes need to optimize their physique for peak performance in their specific activity. The “morphological prototype” is a term that has been used by scientists to describe the optimal physique capable of delivering the best performance in a specific sport (Stewart, 2003). If the prototype has been determined, the measurement of body composition can serve as a method to monitor changes in physique (muscle/fat balance) and then try to make adjustments to ensure that the athlete reaches his/her best physique during competition time.

Ostojic (2003) measured sprint times and body fat percentage during five different periods throughout the season in professional soccer players. He found that body fat percentage was significantly lower at the end of the competitive season compared to the off-season (9.6 % vs 11.5 %,  $P < 0.05$ ). He also found significantly faster 50 m sprint times at the end of the season compared to the off-season (7.1 vs 7.5 s,  $P < 0.05$ ). Throughout the study, there was

a positive correlation between body fat percentage and sprint times ( $r = 0.98$ ,  $P < 0.05$ ). He concluded that a reduction in body fat related to improvements in performance (sprint times).

**Talent identification:** Kinanthropometry also plays an important role in sport science for the purpose of talent identification. It is believed that the shape, size and proportions of the skeleton may give certain athletes a biomechanical advantage over others to succeed in a certain sport. Unlike body composition, skeletal size and shape are not body characteristics that can be changed. Therefore, it is of practical relevance and importance to identify those skeletal characteristics that will favor a specific sport.

The changeable (body composition) and unchangeable (skeletal size, shape and proportion) kinanthropometric characteristics predisposing to success will differ from sport to sport. Bale (1986) reviewed the physique of rugby players in specific positions. Backs were lighter, smaller, less endomorphic and more ectomorphic than the forwards. He suggested that size, shape and body composition play an important part in providing distinct advantage for specific playing positions, especially at elite level of competition where there is a high degree of player specialization. This suggests that the kinanthropometric attributes for success may not only differ from sport to sport, but also within different playing positions in team sports.

From these findings, it is clear that kinanthropometry plays an essential role in the scientific study of all sports. It allows the sport scientist to identify the kinanthropometric attributes to predict performance. Furthermore, it allows the athlete and the coach to make adaptations to his/her training regime to attain the optimal physical attributes for best performance.

#### **D. KINANTHROPOMETRY AND ITS APPLICATION TO KAYAK PERFORMANCE**

A few studies have compared the kinanthropometric profile of paddlers with non-athletes and athletes from other sports, to identify those kinanthropometric characteristics that are important for success in kayaking.

In terms of the two most commonly used kinanthropometric measurements i.e. standing height and body mass, Cermak et al. (1975) were the first researchers to report that the

canoeists ( $n = 17$ ) had higher values for standing height and body mass compared to untrained men ( $n = 72$ ) (No  $P$ -values were reported for differences between the variables). Aitken & Jenkins (1998) found a statistically significantly greater value for body mass ( $P < 0.01$ ), but not for standing height when canoeists ( $n = 15$ ) were compared to age-matched, recreationally active university students ( $n = 15$ ). Tesch & Lindeberg (1984) compared the kinanthropometric characteristics of elite paddlers ( $n = 11$ ) with that of weight lifters (WL), body-builders (BB) and non-athletes (NA), respectively. The paddlers were significantly taller than the WL ( $n = 6$ ), BB ( $n = 8$ ) and NA ( $n = 6$ ) ( $P < 0.05$ ).

When body composition comparisons were made, Cermak et al. (1975) found that canoeists had substantially lower body fat percentages than untrained men (7.1 vs 20%, no  $P$ -values reported). Tesch & Lindeberg (1984) reported that paddlers had significantly less body fat ( $P < 0.05$ ) than NA and WL, but had similar body fat compared to BB. However, Aitken & Jenkins (1998) did not report body fat percentages but found no significant differences in the sum of eight skinfolds between elite paddlers and recreationally active university students.

Considerable differences were found in upper body characteristics in various studies where paddlers were compared with non-athletes and athletes from other sports. Although Cermak et al. (1975) only reported percentage differences and not statistically significant differences, they found higher values for sitting height, chest girth, upper arm girth, trunk breadth and upper arm length when paddlers were compared to untrained men. Tesch & Lindeberg (1984) reported that paddlers had a larger upper arm girth compared to NA ( $P < 0.01$ ) but a smaller upper arm girth compared to WL ( $P < 0.05$ ) and BB ( $P < 0.01$ ). The forearm girth of paddlers was significantly greater compared to NA ( $P < 0.01$ ), but smaller compared to WL ( $P < 0.05$ ) and showed no significant difference compared to BB. The chest girth of paddlers followed the same pattern as forearm girth when it was compared to the three groups. It was significantly greater compared to NA ( $P < 0.01$ ), smaller compared to WL ( $P < 0.05$ ) and showed no significant difference compared to BB. From the study of Aitken & Jenkins (1998), elite paddlers showed statistically significantly greater values for upper arm length, forearm length, biacromial breadth and upper arm girth compared to university students ( $P < 0.01$ ). There were no significant differences in sitting height and arm span between the paddlers and the university students. Physiologically, it is unexplainable why the upper arm length, forearm length and biacromial breadth significantly differed between the paddlers and the control group, but not arm span. This could be due to technical errors in

their measurements of the four different variables. Arm span measurement also revealed the highest inter-individual variability of the four variables measured (highest SD of all four variables).

However, it is possibly more relevant to compare the kinanthropometric profile of successful paddlers with that of less successful paddlers. Fry & Morton (1991) compared selected state paddlers ( $n = 7$ ) with non-selected paddlers ( $n = 31$ ). Selected paddlers were significantly taller (standing and sitting height), heavier and had larger upper arm and forearm girths than non-selected paddlers ( $P < 0.05$ ). There were no significant differences in chest girth, biacromial breadth and the sum of skinfolds between the two groups. At a higher level of competitive performance, Van Someren & Palmer's (2003) study evaluated international and national-level paddlers ( $n = 13$ ). The international-level paddlers had significantly greater values for arm girths (relaxed and tensed bicep and forearm girths), chest girth and mesomorphy than the national-level paddlers ( $P < 0.05$ ). Similar to the previously described study, there were no significant differences in body fat percentages between the two groups. There were no differences in body mass, body height, sitting height, arm span, humerus breadth, endomorphy and ectomorphy between international and national level paddlers.

When paddlers were compared with non-athletes and less successful paddlers, all the abovementioned studies are in agreement that successful paddlers show greater girths of the upper body extremities. This shows that paddlers have greater upper body musculature than non-athletes or less successful paddlers. Compared to non-athletes, Tesch & Lindeberg (1984) and Cermak et al (1975) found that paddlers were taller and had less body fat than non-athletes. But surprisingly, Aitken & Jenkins (1998) contradicted this finding by showing lack of differences in height and body fat (sum of eight skinfolds) between paddlers and non-paddlers. A possible explanation for the lack of difference in body fat is that the "non-athletes" in their study did engage in physical activity, although only recreationally and this may explain why they have less body fat than sedentary individuals. Another reason can be attributed to the different methods used by the different authors to report body fat. Cermak et al. (1975) and Tesch and Lindeberg (1984) reported body fat percentages where Aitken & Jenkins (1998) reported the sum of eight skinfolds. A possible explanation for the lack of difference in height in the study of Aitken & Jenkins (1998) may have been the small sample size. The mean height value of the paddlers was  $184 \pm 4$  cm compared to  $180 \pm 7$  cm of university students. Although this is a difference of at least 4 cm, the difference was not

statistically significant. It is possible that the small sample size of 15 may be responsible for this finding.

The contradictory outcome of Fry & Morton (1991) and Van Someren & Palmer (2003) concerning body height may be attributed to the specific subpopulations used in the study. Due to the high level of competition in both groups, there are very small differences in the performances of international and national level paddlers, hence the non significant differences in height. However, the level of competition between subjects varied more in the study of Fry & Morton (1991).

In order to identify those kinanthropometric characteristics associated with successful performance, a few studies in the literature have correlated these measured variables with kayak race times over various distances, namely, short distances (200 m, 500 m) and long distances (7 km).

Van Someren & Palmer (2003) found significant correlations between kinanthropometric variables and 200 m race times in male paddlers. There were significant correlations between relaxed and tensed upper arm and forearm girths, chest girth, humerus breadth, and 200 m race times for the total group ( $n = 26$ ,  $P < 0.05$ ). In the international level group, the variables that correlated significantly with 200 m race time were sum of skinfolds ( $r = -0.76$ ), body fat ( $r = -0.72$ ) and humerus breadth ( $r = -0.76$ ) (all  $P < 0.05$ ). Humerus breadth was the only variable that significantly predicted 200 m race time ( $R^2 = 0.54$ , SEE = 0.5 s) in international level paddlers. The study of Van Someren & Palmer (2003) highlights the importance of upper body musculature for successful kayak sprint performance. The authors also suggested that the significant correlation of body fat with 200 m race time in international level paddlers can be explained by the differences in training volume and differences in somatotype of the better 200 m paddlers.

In contrast to the above study of Van Someren & Palmer (2003), which was done on male paddlers, Bishop (2000) found no significant correlation between height, weight, sum of skinfolds and body fat percentages, and 500 m race times in competitive female paddlers. A possible explanation for the contradictory outcomes in the correlations between kinanthropometric variables and short distance race times is that Bishop (2000) used female paddlers whereas Van Someren & Palmer (2003) used male paddlers. One can speculate

that the physical attributes for female paddlers to succeed in sprint kayaking are of less importance than for male paddlers. Another reason that may explain why Van Someren & Palmer (2003) found significant correlations with performance and not Bishop (2000), is that Van Someren & Palmer (2003) studied a heterogeneous group of 26 male paddlers (international and national level paddlers) and Bishop (2000) studied a homogeneous group of 9 highly competitive female paddlers. Another explanation for the contradictory results may be the different race distances. Although both distances, 200 m and 500 m, are considered as sprint distances, it is possible that the kinanthropometric attributes necessary for kayak success over 200 m differs from kayak success of 500 m.

When kinanthropometric variables were correlated with long distance kayak events, Olivier & Coetze (2002) found no significant correlation between height, body mass and arm span and 7 km race times in competitive club level paddlers. It can be that anthropometry is of no importance for kayak success over long endurance distances. However there is no additional data to support this finding of Olivier and Coetze (2002). Another limitation to the abovementioned study, they only correlated height, body mass and arm span with endurance performance and did not report any other kinanthropometric measurements and its relationship with kayak performance.

Body mass is a kinanthropometric measurement with much controversy in the assessment of paddler's potential to perform. Originally, it was believed that kayaking is a non-weight bearing sport. Therefore, expressing  $\text{VO}_{2\text{max}}$  as a function of body weight (relative  $\text{VO}_{2\text{max}}$ ) would not be of great significance to kayak success. Sidney & Shephard (1973) believed that absolute  $\text{VO}_{2\text{max}}$  is more important than relative  $\text{VO}_{2\text{max}}$ , because body weight is not lifted greatly during paddling. Tesch (1983) suggested that paddlers with large body dimensions are a prerequisite for kayak success, but the limitations of boat constructions make it difficult to prescribe the optimal body size or mass for paddlers. Fry & Morton (1991) found no significant differences in relative  $\text{VO}_{2\text{max}}$  between selected state and non-selected state paddlers, but they did find a difference in absolute  $\text{VO}_{2\text{max}}$  ( $P < 0.01$ ). Relative and absolute  $\text{VO}_{2\text{max}}$  correlated well with race times, but the correlation with relative  $\text{VO}_{2\text{max}}$  did not add power to the relationship between  $\text{VO}_{2\text{max}}$  and race times. They therefore suggested that a paddler can afford to be a relatively large individual since body weight does not play an important role.

In contrast, both Bishop (2000) and Olivier & Coetze (2002) found better correlations between relative  $\text{VO}_{2\text{max}}$  and race times compared to absolute  $\text{VO}_{2\text{max}}$  and race times. Both authors explained that this is because a heavier individual will sit deeper in the water, which leads to an increase in surface drag. This means that an increased resistance must be overcome to propel the kayak. They argue with original beliefs and state that body mass does influence kayak performance.

The equivocal outcomes of the study of Fry & Morton (1991) and studies of Bishop (2000) and Olivier & Coetze (2002) remain to be explained. One may therefore suggest that body mass will play an ever increasing role as race distance increases (as in sprint and endurance events in athletics) because the heavier paddler needs to overcome a larger resistance for a prolonged period of time in an endurance event. Also, in longer events power may be less important, which means that the paddler does not need to be large. But during sprint events (short distances) the individual can afford to be relatively large, because power plays a more important role and the time spent in the boat is of too short duration for a heavier weight to affect performance. However, this explanation is not supported by most studies. Fry & Morton (1991) do mention that there may be limitations to the general statement that all paddlers can afford to be relatively large, since large individuals will sit deeper in the water, resulting in an increased resistance to overcome to propel the kayak. However, Fry & Morton (1991) correlated absolute and relative  $\text{VO}_{2\text{max}}$  with race distances over 500 m, 1000 m, 10 000 m and 42 km and these distances resemble the race distances studied by Bishop (2000) (500 m) and Olivier & Coetze (2002) (7 km). It might be of importance to note that Fry & Morton (1991) reported that several paddlers were selected into groups competing over more than one distance, since they were successful over short as well as long distances. Thus, paddlers in this study needed to be large for adequate power over short distances, but these large individuals also happened to be successful over long, endurance distances, which was not the case in the other two studies.

In summary, from previous studies it is clear that successful paddlers are characterized by greater upper body musculature and greater lengths of the upper body extremities, compared to non-paddlers. Therefore, the study of the kinanthropometric profile of paddlers will help to identify those athletes predisposed to success (talent identification) and provide a better understanding of how these measurements (such as body mass) will influence kayak performance.

## **CHAPTER THREE**

### **KAYAK ENDURANCE PERFORMANCE**

#### **A. INTRODUCTION**

The development of an air-braked kayak ergometer (K1 Ergo, Australian Sports Commission, Australia) made it possible to assess paddlers more accurately in the laboratory. Most research, using the K1 Ergo specifically, has been done on the physiological attributes of paddlers in relation to short distances or sprint events (Fry & Morton, 1991; Van Someren et al, 2000; Bishop, 2000; Van Someren & Oliver, 2002; Bishop et al, 2002; Van Someren & Palmer, 2003). In contrast, very little research exists on paddlers competing in longer distances or endurance events, such as the marathon (42 km) (Olivier & Coetze, 2002; Fry & Morton, 1991).

#### **B. KAYAK ERGOMETER**

It is imperative that equipment used in a laboratory setting to assess an athlete's physiological status should simulate the precise action of that specific sport in the natural environment. The use of arm crank ergometer and the rowing ergometer to assess paddlers has been criticized for lack of specificity (Pyke et al., 1973).

Pyke et al. (1973) developed an isokinetic kayak ergometer modified from a Monark bicycle ergometer. The pedal arms (adjustable for each subject) were extended and attached with ropes to the paddle. A pulley system was added to the rear of the subject to allow the paddler to push with his recovery arm while pulling with the working arm, in order to simulate an on-water situation. But, some researchers questioned the reliability of the use of isokinetic kayak ergometers for physiological and performance testing, with equivocal outcomes. Van Someren & Dunbar (1996) studied the use of an isokinetic kayak ergometer for the determination of blood lactate profiles in international level paddlers. Their results showed that the isokinetic ergometer did not demonstrate sufficient reproducibility in terms of the power-La relationship ( $r = 0.70$  and  $r = 0.74$  at fixed La values of 2 and  $4 \text{ mmol.L}^{-1}$ , respectively) and was unacceptable for the long-term monitoring of training progression.

The air-braked kayak ergometer (K1 Ergo, Australian Sports Commission, Australia) is currently the ergometer of choice for paddlers and physiologists for training and exercise testing (Van Someren et al., 2000). The K1 Ergo is scientifically more appropriate for exercise testing, as it is interfaced with a personal computer to measure power output, total work done, stroke rate and stroke length. This provides real time feedback for the paddler during testing, as well as the opportunity to analyze the acquired data after a performance test. The reliability of the K1 Ergo has been reported to be high. Van Someren & Dunbar (1997) investigated the use of the K1 Ergo during supramaximal 30 s tests on nine senior sprint paddlers. They found that the ergometer was reliable in both mechanical and physiological parameters measured. The correlations for test-retest values on peak power, total work done and peak heart rate were  $r = 0.99$ ,  $r = 0.98$  and  $r = 0.99$ , respectively. Therefore, the K1 Ergo is suitable for supramaximal testing of paddlers.

Van Someren et al. (2000) also compared the physiological responses on the K1 Ergo to open water kayaking. The major finding of this investigation was that the distance covered in a 4 min open water K1 performance trial was highly correlated with work done in 4 min simulated trial on the K1 Ergo in the laboratory ( $R^2 = 0.86$ ). There were also no significant differences in subjects' peak VE, Peak  $\text{VO}_2$ , peak HR and post-exercise blood lactate concentration between the open water trial and the laboratory trial. They concluded that the K1 Ergo accurately simulates the physiological demands of short-term high intensity kayaking.

These findings evidently show that the K1 Ergo can be acknowledged as the most valid and reliable apparatus for physiological testing in a laboratory setting.

## C. PHYSIOLOGICAL VARIABLES OF IMPORTANCE DURING INCREMENTAL EXERCISE TESTING

### 1. Maximum aerobic capacity ( $\text{VO}_{2\max}$ )

#### 1.1 Current concepts of $\text{VO}_{2\max}$

Hill and Lupton (1923) were the first physiologists who demonstrated that as exercise intensity increases, the oxygen cost rises as a linear function of the exercise intensity. Given

this linear relationship between oxygen consumption and exercise intensity, it is only logical to believe that athletes who achieve the highest exercise intensities, regardless of the type of exercise, will have the greatest capacity for oxygen consumption (Noakes, 2001). Furthermore, the athlete with the highest  $\text{VO}_{2\text{max}}$ , may be able to work at the highest work rate for a prolonged period of time, and may perform the best in a race or event, unless other factors also contribute to performance.

It was subsequently believed that  $\text{VO}_{2\text{max}}$  is the single, most important predictor of endurance performance. Although many studies have shown that  $\text{VO}_{2\text{max}}$  can predict how well an athlete will perform in an endurance event, all of these studies focused on athletes with very different abilities, i.e. heterogenous groups (Noakes, 2001). In reality, athletes with similar abilities (running performance times), may actually differ extensively with regard to  $\text{VO}_{2\text{max}}$ . This evidently makes  $\text{VO}_{2\text{max}}$  not a good predictor of performance in homogenous groups (Costill & Winrow, 1970; Coetzer et al., 1993; Abe et al., 1998).

Nevertheless, the highest  $\text{VO}_{2\text{max}}$  values reported, are those of elite athletes ( $79 - 93 \text{ ml.kg}^{-1}.\text{min}^{-1}$ ), whereas the average healthy young man has a  $\text{VO}_{2\text{max}}$  of at least 60% lower ( $45 - 55 \text{ ml.kg}^{-1}.\text{min}^{-1}$ ) than that of elite athletes. Healthy people can improve their  $\text{VO}_{2\text{max}}$  by 5 – 15%, through intensive training (Daniels et al., 1978). Thus, a person with a very low  $\text{VO}_{2\text{max}}$  can train as much as he/she likes, but will never achieve a value anywhere near that of elite athletes (Noakes, 2001). Thus,  $\text{VO}_{2\text{max}}$  can be considered as an indirect measure of potential for success in endurance sport, but it is in general not a good predictor of performance. It is also important to emphasize that  $\text{VO}_{2\text{max}}$  is the result of the peak work rate achieved and not the cause of the peak work rate achieved (Noakes, 2001). Therefore, the peak work rate achieved during a laboratory test is more important in terms of the prediction of performance, than  $\text{VO}_{2\text{max}}$ .

## 1.2 $\text{VO}_{2\text{max}}$ and different muscle groups

The  $\text{VO}_{2\text{max}}$  achieved by an individual, through arm exercise, will differ from the  $\text{VO}_{2\text{max}}$  achieved by the same individual through leg exercise. One of the first findings of this phenomenon was made by Astrand and Saltin (1961), who compared arm cycling with leg cycling. They concluded that the  $\text{VO}_{2\text{max}}$  values during maximal work of the arms were about 70% of the  $\text{VO}_{2\text{max}}$  values reached during maximal work of the legs. Pyke et al.

(1973) compared the metabolic and circulatory responses of kayak paddlers during work on both a canoeing and bicycle ergometer. It was concluded that maximal aerobic power measured on the canoeing ergometer was approximately 68% of that determined on the bicycle ergometer. Tesch et al. (1976) found that the  $\text{VO}_{2\text{max}}$  achieved during arm exercise on a modified bicycle ergometer was 85% of the  $\text{VO}_{2\text{max}}$  achieved on a treadmill. Tesch & Karlson (1984) compared the  $\text{VO}_{2\text{max}}$  achieved during arm crank ergometry with that of treadmill running in elite flat water kayak paddlers (Swedish national team). They found that  $\text{VO}_{2\text{max}}$  during arm crank exercise was 84.5% of the  $\text{VO}_{2\text{max}}$  during running. Bunc & Heller (1994) reported that the  $\text{VO}_{2\text{max}}$  achieved during arm exercise on a customized paddling ergometer was 88.7% of the  $\text{VO}_{2\text{max}}$  achieved during leg exercise on a bicycle ergometer ( $P < 0.05$ ). This indicates that  $\text{VO}_{2\text{max}}$  is exercise mode-specific. Generally,  $\text{VO}_{2\text{max}}$  is higher with activities involving a large muscle mass (i.e. the legs) compared to activities involving a smaller muscle mass (i.e. the arms).

Another phenomenon is that different types of apparatus used for determination of  $\text{VO}_{2\text{max}}$ , even if the mode of exercise, the arm crank frequency and the power output are equivalent, will elicit different  $\text{VO}_2$  responses in the same individual. Kang et al. (1999) compared arm crank exercise on an arm ergometer and a modified leg ergometer. They found that at a given level of  $\text{VO}_2$ , the corresponding power output was consistently lower on the arm ergometer, compared to the modified leg ergometer. The magnitude of the difference in power output ranged from 5 – 10 W (or 30 – 60  $\text{kgm} \cdot \text{min}^{-1}$ ) and was directly proportional to the level of  $\text{VO}_2$ . This makes direct comparison between studies using different types of arm ergometers difficult.

### 1.3 $\text{VO}_{2\text{max}}$ and different test protocols

In general a graded, progressive incremental test, on a sport-specific ergometer, is used to determine  $\text{VO}_{2\text{max}}$ . The incremental test starts at a low work rate; the work rate is then progressively increased at regular intervals until the subject reaches exhaustion. Just before exhaustion, the individual will reach his/her maximal work rate. The highest sustainable oxygen consumption during the maximal work rate will be identified as the  $\text{VO}_{2\text{max}}$ .

Although an individual is capable of reaching his/her maximal work rate within a few seconds, the protocol for testing  $\text{VO}_{2\text{max}}$  is formulated to last between 8 – 15 min (Noakes,

2001). The longer protocol will allow sufficient time for oxygen consumption to reach its maximum.

Evidence in the literature exists that test protocols of different duration and workload increments elicit different  $\text{VO}_{2\text{max}}$  values for the same individual (McLellan, 1985; Buchfuhrer et al., 1983). Buchfuhrer et al. (1983) found lower  $\text{VO}_{2\text{max}}$  values during longer test conditions ( $> 10$  min) and suggested that this could be due to an increased thermoregulatory load, greater dehydration or ventilatory muscle fatigue. They therefore suggested that 10 min would be an optimal duration for an incremental test on a cycle ergometer with workload increments of 30 W every 1 min. Olivier & Coetzee (2002) assessed male kayak paddlers on an arm crank ergometer. They explained that they chose increments of 15 W per minute to reduce the likelihood of local fatigue being the reason for cessation of exercise rather than aerobic factors.

If the only purpose of the incremental test is to determine  $\text{VO}_{2\text{max}}$ , 1 min will be the preferred increment duration. But, if one also wants to determine the lactate threshold, the workload increments need to be longer ( $> 2$  min) as oxygen consumption needs to reach a steady state at each new workload, before a valid blood sample can be taken for the determination of blood lactate concentration (Yoshida, 1984).

Currently, there is no indication in the literature of the optimal duration and magnitude of the workload increment during an incremental test on the K1 Ergo. Previous investigators used different test protocols for determination of lactate threshold and maximal oxygen consumption. Van Someren et al. (2000), Van Someren & Palmer (2003) and Van Someren & Oliver (2002) used increments of 20 W every 4 min (commencing at 80 W) with 30 s rest intervals between workloads (for blood sampling) until a lactate concentration of  $4 \text{ mmol.L}^{-1}$  was reached. Thereafter workload increased every minute until the subject reached exhaustion.  $\text{VO}_{2\text{max}}$  was identified as the highest value averaged over 1 min. Bishop et al. (2002) used increments of 25 W every 5 min (commencing at 50 W) with 1 min rest intervals between workloads, for blood sampling. The test continued until the paddler could no longer maintain the required power output. The highest four consecutive 15 s  $\text{VO}_2$  values were averaged and identified as  $\text{VO}_{2\text{max}}$ .

## 2. The lactate threshold (LT)

### 2.1 Current concepts of the lactate threshold

Lactate was first defined as an end-product of glycogen breakdown in the exercising muscles when the oxygen supply to the muscle became inadequate (Fletcher & Hopkins, 1907). But it is now known that lactate is a natural product of carbohydrate metabolism in muscles, even when their oxygen supply is more than adequate (Noakes, 2001). Blood lactate concentrations rise as a continuous function of the exercise intensity without showing an abrupt threshold effect (Campbell et al., 1989). Rather, lactate concentrations rise exponentially without any evidence of a threshold phenomenon (Noakes, 2001). Increases in lactate concentration imply that there is a greater rise in the rate of lactate production than the rate of lactate removal. This point is generally defined as the “lactate threshold”.

It was also noted that carbon dioxide production ( $VCO_2$ ) and minute ventilation (VE) increase concurrently with blood lactate concentration, as the level of exercise intensity increases. This sudden increase in  $VCO_2$  was originally called the anaerobic threshold (Wasserman & McIlroy, 1964), while the increase in VE was called the ventilatory threshold (VT) (Wasserman et al., 1973; Davis et al., 1976).

Wasserman (1984) proposed that the increase in the volume of expired carbon dioxide ( $VCO_2$ ) represented  $CO_2$  buffering as a result of lactate accumulation from increased anaerobic metabolism. VE increases to compensate for the resultant metabolic acidosis, hence the sudden (non-linear) increase in VE (Wasserman et al., 1973).

However, evidence in the literature suggests that this relationship between an increase in expired gas and lactate accumulation is coincidental. One such study examined this relationship in patients with McArdle’s Disease (a genetic disorder in which patients lack the enzyme for catabolising glycogen into lactate). The McArdle’s patients experienced an increase in pulmonary gas exchange similar to controls at a similar exercise intensity. However, they showed no increase in blood lactate concentration as exercise intensity increased, whereas controls showed a lactate threshold at 60% of  $VO_{2\max}$  (Hagberg et al., 1982).

The work by Hagberg et al. (1982) shows that a sudden increase in the volume of expired gas is not synonymous with an increase in blood lactate concentration and should be seen as two separate, but concurrent reactions to an increase in exercise intensity. Therefore, the sudden increase in the rate of ventilation and  $\text{VCO}_2$  was termed, the “ventilatory threshold” and not “anaerobic threshold” (Hagberg et al., 1982).

## 2.2 Determination of lactate threshold

Numerous methods exist for the determination of LT. This is mainly due to the fact that scientists used different terminology to describe basically the same event, i.e. lactate threshold. The following describes some of the definitions of invasive methods determined using lactate threshold:

- i) LT is defined as the highest  $\text{VO}_2$  that can be attained during incremental exercise before an elevation in blood lactate is observed (Yoshida, 1984).
- ii) LT is the  $\text{VO}_2$  when the blood lactate concentration rises  $1 \text{ mmol.L}^{-1}$  above baseline blood lactate concentration (Coyle et al., 1983).
- iii) LT is determined as a blood lactate concentration of  $2.5 \text{ mmol.L}^{-1}$  (Hagberg et al., 1982)
- iv) Several investigators suggested that LT occurs at a fixed-blood lactate value of  $4 \text{ mmol.L}^{-1}$ . This has been termed the onset of blood lactate accumulation or *OBLA* (Heck et al., 1985; Sjodin & Jacobs, 1981; Yoshida, 1984). This absolute concentration is recognized as a maximum lactate concentration where there is still a balance between lactate production and lactate removal during continuous, incremental exercise.
- v) Borch et al. (1993) suggested that the treadmill speed that elicits a blood lactate concentration of  $3 \text{ mmol.L}^{-1}$  might be the best measure of an athlete’s LT.
- vi) The  $D_{\max}$  method determines the LT as the point on the polynomial regression curve that yields the maximal perpendicular distance to the straight line formed by the lactate inflection point (which is the first increase in lactate concentration above the resting level) and the final lactate point (Bishop, 2000; Bishop et al., 2002).
- vii) Stegmann et al. (1981) introduced the individual anaerobic threshold (IAT). IAT was defined as the workload corresponding to the steady state between diffusion of

- lactate into the blood and maximal elimination from the blood and the muscles and requires more than one exercise test to determine.
- viii) Bishop (2004) later identified the lactate inflection point (LI) as the first increase in lactate concentration greater than  $0.4 \text{ mmol.L}^{-1}$  above the resting level.

Irrespective of the definition and methodology, the assessment of lactate threshold either involves a continuous incremental protocol, or a series of discontinuous 10 minute exercise bouts. Weltman et al. (1990) compared a 3 min continuous incremental protocol ( $10 \text{ m.min}^{-1}$  increments) to nine 10 min exercise bouts. They measured  $\text{VO}_2$  and velocity at 2, 2.5 and 4  $\text{mmol.L}^{-1}$  blood lactate concentration to determine LT. Measurements were similar during both assessments, therefore both protocols were considered equally accurate and valid.

In previous studies, using kayak ergometry, LT was identified as the work rate preceding an increase in blood lactate concentration of  $> 1 \text{ mmol.L}^{-1}$  (Van Someren & Oliver, 2002; Van Someren & Palmer, 2003) or using the modified  $D_{\max}$  method.

Numerous methods also exist for the determination of the ventilatory threshold. One such method was introduced by Wasserman et al. (1973) who defined the “anaerobic threshold” as the point where a non-linear increase in minute ventilation (VE) occurred when plotted against  $\text{VO}_2$ , and expressed as a percentage of  $\text{VO}_{2\max}$  (% $\text{VO}_{2\max}$ ).

### 2.3 The significance of lactate threshold

Noakes (2001) suggested that the practical relevance of the lactate threshold is that there is a relationship between this variable and performance and that it has been used to monitor fitness.

For example, considerable research on running performance showed that the average running speed that runners could sustain during middle- and long-distance races closely resembled their treadmill speeds at lactate threshold. Sjodin & Jacobs (1981) examined the relationship between the treadmill velocity at which “the onset of blood lactate accumulation” ( $V_{\text{OBLA}}$ ) occurred and mean running velocity during a marathon ( $V_M$ ).  $V_{\text{OBLA}}$  significantly correlated with  $V_M$  ( $r = 0.96$ ,  $P < 0.001$ ), therefore, they concluded that marathon performance was closely related to the individual velocity at which OBLA occurred. Lehman et al. (1983)

examined the correlation between race times during a 30 km cross-country run and the minimum lactate equivalent, which indicates the maximum work rate without significant blood lactate increase. They found a significant correlation between these two variables ( $r = 0.69$ ,  $P < 0.05$ ).

Using the lactate threshold as a predictor of performance has also been investigated in kayak paddlers. Bishop (2000), using the 6<sup>th</sup> definition for LT (see page 21) described that the  $D_{max}$  strongly correlated with the 500 m race time in female, high-performance kayak paddlers ( $r = -0.89$ ,  $P < 0.05$ ).

Lactate threshold can be used to monitor changes in the athlete's fitness level. Sjodin et al. (1981) found, by using regression analysis, that capillary density accounted for 61% of the variation in  $V_{OBLA}$  (treadmill velocity at a lactate concentration of 4 mmol.L<sup>-1</sup>). They also found that the absolute training distance (km) accounted for 77% of the variation in  $V_{OBLA}$ . From this study, it is clear that training volume, peripheral adaptation and  $V_{OBLA}$  are interrelated. An increase in endurance training volume will lead to an increase in muscle enzyme activity and capillary density (Sjodin et al., 1981). These adaptations in the working muscles cause an improvement in lactate threshold ( $V_{OBLA}$ ), which is therefore an indication of the improvement in an athlete's fitness status.

The use of the lactate threshold as an indication of an athlete's fitness status has also been investigated in kayak paddlers. Tesch & Lindeberg (1984) found that male kayak paddlers had significantly lower blood lactate levels at all workloads, during a submaximal arm crank ergometer test, than non-athletes, weight lifters and body builders ( $P < 0.05$ ). Although not specifically investigated, they attributed the lower blood lactate levels to peripheral metabolic adaptations in the arm muscles only with kayak endurance training.

A third significance of the lactate threshold is that it can be used to establish specific exercise intensities for endurance training. The purpose of endurance training is to improve aerobic fitness and subsequently, improve endurance performance, but the benefits of training can be compromised if the intensity at which the athlete trains, is too low or too high. Some researchers have suggested that physiological variables at lactate threshold can be used to monitor training intensities and should provide the optimal training intensities to improve aerobic fitness (Henritze et al., 1985; Weltman et al., 1992).

In kayak paddling the identification of physiological markers for training intensity has already been investigated. Bishop (2004) determined the power output at the lactate inflection point (LI) (greater than 0.4 mmol.L<sup>-1</sup> increase from resting blood lactate concentration levels) during an incremental test on the K1 Ergo in state-level kayak paddlers. The paddlers then performed a 20 min constant load test at LI power output on the K1 Ergo. There were no significant differences between the mean values for heart rate (HR), oxygen consumption (VO<sub>2</sub>) and blood lactate concentration [La] at LI derived from the incremental test, and those measured during the constant load test ( $P > 0.05$ ). He concluded that these physiological variables (HR, VO<sub>2</sub> and [La]) can be used as valid markers to estimate exercise intensity for endurance training, during kayak ergometer exercise. Whether these variables can be used as markers for training intensities on open water must still be validated. Also, whether training at that intensity results in training adaptations in paddlers can only be established in a longitudinal study.

### **3. Peak power output (PPO)**

#### **3.1 Definition and determination of peak power output**

Peak power output (PPO) is defined as the maximum work rate an athlete can achieve before fatigue sets in during a progressive incremental exercise test. Different exercise modes during incremental testing elicit different types of maximum work rates. During incremental testing on a treadmill, maximum work rate is the maximum speed (km.h<sup>-1</sup>) which the athlete can achieve before termination and is known as the Peak Treadmill Velocity (PTV). During incremental testing on a cycle ergometer, maximum work rate is the maximum workload on the pedals which the cyclist can overcome while keeping the pedalling rate at a fixed cadence. This maximum work rate is known as the Peak Power Output (PPO in W).

During incremental exercise testing on a wind-braked kayak ergometer, maximum work rate is the maximum wind-braked resistance, which the paddler can overcome by pulling harder with the paddle to elicit a higher stroke rate. Stroke rate is directly proportional to power output. The paddler is instructed to manually maintain the predetermined power output (reflected on the kayak monitor) by increasing his/her stroke rate during the incremental test. Wind-break resistance is not adjustable by outside mechanisms. Thus the maximum stroke

rate will generate the maximum work rate on the kayak ergometer and this maximum work rate is known as the Peak Power Output (PPO in W).

Maximum work rate must be sustained for a period of time during the last increment of the test to be truly recognized as the peak power output. The power output during incremental testing on an electronically controlled cycle ergometer is fixed at each increment and independent of the pedaling speed. If a cyclist fails to complete the increment at the last workload, PPO is calculated with the following formula:

$$PPO = W_{com} + t_{com} / t_{inc} \times \Delta W \dots \dots \dots \text{Eq. 3.1,}$$

where  $W_{com}$  is the last completed workload,  $t_{com}$  is the time (s) completed in the unfinished work load,  $t_{inc}$  is the increment duration (s) and  $\Delta W$  is the work load increment (Kuipers et al., 1985).

In literature concerning kayak ergometry, the method for determining PPO has not yet been fully described. One study mentioned that PPO was determined as the highest value for PPO averaged over one minute (Van Someren & Palmer, 2003). During kayak ergometry power output is continuously recorded with every stroke. It simplifies the determination of PPO during incremental testing, since the highest values over a consecutive given period of time for power output during the last workload can easily be averaged.

### 3.2 Significance of peak power output

Widespread evidence in the literature shows that maximum work rate or PPO is the single best predictor of performance and athletic potential. In running and cycling this phenomenon has been thoroughly investigated. In running, Grant et al. (1997) assessed the relationship between velocity at  $VO_{2\max}$  ( $v-VO_{2\max}$ ) and the running velocity during a 3 km time trial (v-3km) on an indoor track in 16 well-trained middle- and long-distance runners. They found that  $v-VO_{2\max}$  correlated well with v-3km ( $r = 0.86, P < 0.05$ ). Cunningham (1990) found a significant correlation between velocity at  $VO_{2\max}$  and the actual running time in a 5 km race ( $r = 0.77, P < 0.001$ ) in female high-school runners. In cycling, Bentley & McNaughton (2003) found a strong relationship between PPO achieved during an

incremental test on a cycle ergometer and the average sustained power output during a 90 min cycle time trial on the bicycle ergometer ( $r = 0.94$ ,  $P < 0.01$ ).

It is fair to assume that an athlete with a larger body size will physically be stronger and will reach a higher PPO than a smaller athlete. Therefore, PPO should be expressed as a function of body weight. In sport where the amount of body weight may influence performance, e.g. hill climbing in cycling, the PPO-to-weight-ratio is an important index for performance prediction. When PPO alone is correlated with performance, it can show a weak relationship with performance, but when the same PPO is expressed as a function of body weight ( $\text{W} \cdot \text{kg}^{-1}$ ), it may actually show a stronger relationship. Balmer et al. (2000) found that PPO achieved during an incremental maximal aerobic power test showed a weak correlation with outdoor 16.1 km cycling performance time ( $r = 0.46$ ,  $P = 0.07$ ) in competitive cyclists. However, when PPO was expressed as a function of body weight ( $\text{W} \cdot \text{kg}^{-1}$ ), a significant correlation was found with the 16.1 km performance time ( $r = 0.64$ ,  $P < 0.01$ ).

Two previous studies mentioned the relationship between PPO and PPO/weight and performance in kayak paddlers. Bishop (2000) investigated the relationship between physiological variables and a 500 m flat-water kayak performance ( $K_{500}$ ) in female high-performance paddlers ( $n = 9$ ). The PPO achieved at the end of the incremental exercise test correlated poorly with the  $K_{500}$  time ( $r = -0.56$ ,  $P > 0.05$ ). But the PPO-to-weight ratio achieved at the end of the incremental exercise test correlated well with the  $K_{500}$  time ( $r = -0.75$ ,  $P < 0.05$ ) and may thus be a good predictor of performance for this distance.

Van Someren & Palmer (2003) examined the relationship between the physiological profile in sprint kayak paddlers ( $n = 26$ ) with 200 m race performance. The maximum power output in Watt (calculated as the highest value averaged over a 1 min period) achieved during the incremental exercise test correlated poorly ( $r = -0.32$ ,  $P > 0.05$ ) with 200 m race time. The possibility exists that maximum power to weight could have shown a better correlation with 200 m race time, but it was not reported. However, the distance for the performance test is also shorter, thus a similar finding to Bishop (2000) should not be expected.

Fry & Morton (1991) examined the physiological attributes of different elite flat-water kayak paddlers ( $n = 38$ ) competing in 500 m, 1 000 m and 42 km races, respectively. The maximum time (or time to exhaustion) that could be sustained on the kayak ergometer

during the incremental test showed a stronger relationship with the 42 km race time ( $r = -0.84$ ,  $P < 0.05$ ) than with the 500 m and 1000 m race times ( $r = -0.51$  and  $r = 0.64$ , respectively,  $P < 0.05$ ). If it is assumed that time to exhaustion during the incremental test is directly proportional to the power output, it means that the paddler who sustains exercise for a longer period of time, also reaches a higher PPO.

From the abovementioned studies it seems that absolute PPO is not a good predictor of kayak sprint performance and that the latter may be better correlated with relative PPO ( $\text{W} \cdot \text{kg}^{-1}$ ), or perhaps a measure of anaerobic capacity, i.e. short bursts of maximal exercise. It is therefore possible that PPO measured during incremental exercise is a better indication of the maximal work rate which the paddler can sustain for a prolonged period of time. Thus, it can be hypothesized that absolute PPO has a stronger relationship with kayak performance over longer, endurance distances and becomes a more important predictor of performance as race distance increases.

### 3.3 Practical problems with peak power output

Practical problems exist with the interpretation of PPO, because the measurement of PPO is both exercise mode specific and test protocol specific. These problems must be taken in consideration when comparisons are made between different athlete groups or when the peak power outputs of an athlete obtained from different protocols are compared.

It should be noted that the PPO achieved during an incremental exercise test should theoretically always be lower during arm work compared to leg work. Bunc & Heller (1994) found a significant difference between PPO achieved during an incremental test on a bicycle ergometer and a paddling ergometer ( $P < 0.01$ ) in female flat-water kayak paddlers. Billat et al. (1996) compared power output for different sports in national class sportsmen. They found that the power output at  $\text{VO}_{2\text{max}}$  for kayak paddlers on a non-specific kayak ergometer was only 57% of the power output at  $\text{VO}_{2\text{max}}$  for cyclists ( $P < 0.05$ ). They reported that this finding can be explained by the smaller muscle mass (muscles of the arms and shoulders) involved in the kayak paddling action compared to the larger muscle mass of the legs involved in cycling.

Previous researchers have questioned the use of different protocols to determine PPO. Bentley & McNaughton (2003) found a significantly higher PPO during a short incremental test (60 s increments commencing at 150 W) compared to a long incremental test (3 min increments commencing at 50% PPO obtained during short test) ( $P < 0.01$ ). From these findings it can be concluded that when PPO is achieved during different exercise protocols, the PPO data will not be comparable. However, Weltman et al. (1990) reported a test-retest correlation coefficient of  $r = 0.96$  for peak velocity obtained during a continuous incremental treadmill protocol on two separate occasions (one week apart). He suggested that it will be valid to compare the PPO of individuals obtained from the same test protocols (same increment and duration), as the reproducibility of the measurement is high.

In summary, a few limitations exist in the determination of PPO during incremental exercise testing using kayak ergometry. Firstly, no standardized method for the calculation of PPO during kayak ergometry is fully described in the literature. Only Van Someren & Palmer (2003) mentioned that they calculated PPO as the highest values averaged over a 1 min period. Secondly, the reproducibility of PPO during incremental exercise on the K1 Ergo has not yet been determined. This should be done despite the fact that the reproducibility of PPO or maximum work rate is high for other modalities of exercise (Balmer et al., 2000; Weltman et al., 1990).

#### **4. Maximum heart rate**

Maximum Heart Rate ( $HR_{max}$ ) is defined as the highest heart rate (HR) achieved during a progressive incremental test, measured in beats per minute (bpm). The practical relevance for measuring  $HR_{max}$  in athletes is to establish a method for monitoring intensity during training, which is critical for any serious athlete. In high performance athletes training intensity must be carefully monitored to prevent overtraining, or to prevent the athlete from training at intensities too low to benefit from the training (Gilman & Wells, 1993).

With the invention of telemetric heart rate monitors, HR monitoring can easily, accurately and cost effectively be used to monitor training intensity. In general, different HR zones (expressed as a percentage of  $HR_{max}$  or as HR at, below or above lactate threshold) are determined from the athlete's maximum measured HR and categorized as easy, moderate or hard training intensities (Gilman, 1996). Caution should be taken when heart rate is used to

reflect training intensity, as many factors can cause a variation in HR at the same intensity of effort. Some of the factors that will cause an increase in heart rate, other than an increase in the work rate are: cardiovascular drift (a rise in submaximal HR during constant load exercise exceeding 20 min), psychological stress, environmental heat stress and dehydration (Gilman, 1996). Furthermore, HR expressed as a percentage of  $HR_{max}$ , does not necessarily reflect a similar percentage of  $VO_{2max}$ . Thus, HR at a given intensity does not accurately reflect the metabolic stress experienced by the athlete (Gilman, 1996).

In kayak paddlers, HR measured in a neutral laboratory setting will most likely differ from the measured HR in the open field at the same intensity, due to additional stress factors present in the environment. Van Someren et al. (2000) compared different physiological variables (including HR) measured during a 4 min sprint on the K1 Ergo (in a laboratory) with a 4 min sprint on the open water. They found significantly higher heart rates during the first minute of the sprint on open water ( $178 \pm 6$  vs  $170 \pm 7$  bpm at 60 s,  $P < 0.05$ ). Thereafter, HR reached a steady state and showed no significant difference with that measured on the K1 Ergo. They concluded that this initial difference may be due to different warm-up strategies. Although subjects were instructed to follow the same warm-up procedure during both trials, it could not be fully controlled. The difference could also have been due to differences in mechanical efficiency between the two trials. Other factors associated with the environment could possibly also contribute to the differences in heart rate during the initial stages of the sprint, such as psychological stress on the water, extra energy cost for the paddler to stabilize himself in the kayak or the weather conditions, or a combination of these factors. Bishop (2004) reported that HR at lactate threshold can be used as a marker for training intensity during a 20 min constant load K1 Ergo exercise, but he suggested that further research is required to determine the validity of HR as a marker of exercise intensity under different environmental conditions.

Whether or not the  $HR_{max}$  obtained during maximal arm exercise is lower than during leg exercise has been investigated. Pyke et al. (1973) reported that maximum heart rate determined on a bicycle ergometer was never reached by canoeists ( $n = 20$ ) while working on a canoeing ergometer ( $P < 0.01$ ). This can possibly be explained by the use of a smaller muscle mass and subsequently a lower energy cost during arm exercise, the same reason why  $VO_{2max}$  is lower during arm work compared to leg work. However, this does not always appear to be the case. Larsson et al. (1988) reported that maximum HR reached by elite

Danish male paddlers ( $n = 20$ ) during exercise on a kayak ergometer, an arm crank ergometer, and on a bicycle ergometer were 186 (178-204), 189 (177-200) and 185 (180-200) bpm, respectively ( $P < 0.05$ ). Tesch (1983) also reported that national Swedish kayak paddlers ( $n = 11$ ) reached similar maximum heart rates during continuous graded treadmill running ( $190 \pm 9$  bpm), and arm cranking ( $190 \pm 8$  bpm), and during outdoor maximal kayak paddling for 6 min ( $192 \pm 9$  bpm) ( $P > 0.05$ ).

The reliability of measuring  $HR_{max}$  during incremental exercise has been reported as high. Weltman et al. (1990) reported a test-retest correlation coefficient of  $r = 0.96$  for  $HR_{max}$  obtained during incremental exercise on a treadmill. The reliability of  $HR_{max}$  during incremental exercise on the K1 Ergo has not yet been reported, but Van Someren & Dunbar (1997) reported a test-retest correlation coefficient of  $r = 0.989$  for peak HR (bpm) achieved during a 30 s supra-maximal sprint test on a K1 Ergo.

## **5. Conclusion**

Incremental exercise testing in the laboratory allows the opportunity to measure important physiological variables at different work intensities and at maximum work rate, which provides the athlete, the coach and the exercise scientist with information of great significance. Physiological assessment of various groups of athletes during incremental exercise also provide the exercise scientist with information on which physiological attributes are important for performance in a specific sport and a better understanding of the physiological requirements for different types of exercise.

## **D. KAYAK ENDURANCE PERFORMANCE TESTS**

### **1. Significance of endurance performance tests**

In physiological exercise testing, performance tests allow the researcher to measure the physiological response of the athlete as it would happen during competition, since performance tests resemble competition situations and not incremental exercise testing. The evaluation of performance in a laboratory setting is done to distinguish between the different physiological demands of different sports and different events within a sport. A measure of performance in a standardized test can be related to different physiological,

kinanthropometric and biomechanical variables tested in the laboratory, to identify the variables that contribute to performance success. These attributes can then be classified as predictors of performance.

In order to accurately identify the attributes of performance or to accurately appraise the influence of an intervention, the endurance performance test must be valid and reliable. Researchers traditionally used “time to exhaustion” at a fixed percentage of  $\text{VO}_{2\text{max}}$  as the measure of endurance performance. Some studies have reported that “time to exhaustion” is a reliable measure of performance. Laursen et al. (2003) found that repeated measurements (one week apart) of time to exhaustion, at the power output at  $\text{VO}_{2\text{max}}$ , were reproducible ( $r = 0.88$ ,  $P < 0.001$ ) in highly trained cyclists.

Other researchers, however, have questioned the reliability of “time to exhaustion”, due to its high variability and proposed that time trial protocols may result in better performance evaluation. Jeukendrup et al. (1996) divided thirty well-trained cyclists into three groups. Each group performed one of three different endurance performance tests (A, B or C). Protocol A was a ‘time to exhaustion’ test at 75% of  $\text{VO}_{2\text{max}}$ . In protocol B subjects performed as much work as possible in 15 min after a preload of 45 min at 70% of maximal workload. In protocol C subjects had to complete a preset amount of work as fast as possible. Each protocol was repeated 5 times. The coefficient of variation (CV) for each protocol was  $\text{CV(A)} = 26.6\%$ ,  $\text{CV(B)} = 3.5\%$  and  $\text{CV(C)} = 3.4\%$ . Therefore, time to fatigue was a less reliable performance test than a time trial protocol in trained cyclists. Jeukendrup et al. (1996) suggested that endurance performance tests with a known “endpoint” (a certain time or amount of work) appear to be highly reproducible. They also suggested that performance tests with an “open end” (time to exhaustion) can be influenced by psychological factors, such as motivation and boredom. The poor reliability of “time to exhaustion” is further due to the unusual type of exercise, because this test does not simulate the actual competition conditions in endurance events. Hickey et al. (1992) proposed that time trial protocols allow the assessment of endurance “performance” as it happens in competition situations as opposed to “time to exhaustion” tests which rather assess endurance “capacity”.

The reliability and validity of a time trial test as a measure of cycling endurance performance has been thoroughly investigated in the literature. Bishop (1997) investigated the reliability

of a 1-h cycling endurance performance test. Subjects had to complete two trials in which they had to generate the highest possible power output throughout 60 min on a wind-braked cycle ergometer. The two trials were separated by 1 week. The intraclass correlation coefficient for average power output was 0.97 and the coefficient of variation was 2.7%. Coyle et al. (1991) reported the validity of a 1-h endurance performance test in elite-national class cyclists. Actual road racing over a 40 km time trial was highly correlated with the average power output during the 1-h laboratory performance test ( $r = -0.88$ ,  $P < 0.001$ ). These two studies showed that a 1-h endurance performance test during cycling is a valid and highly reliable measure of endurance performance.

## **2. Kayak performance tests**

No studies in the literature exist on the measurement of kayak endurance performance by means of a time trial in a laboratory setting. The validity and reliability of kayak laboratory performance tests has also not been studied. The only study available in the literature which investigated “time to exhaustion” at a fixed power output (the power output at  $\text{VO}_{2\text{max}}$ ) in kayaking, was Billat et al. (1996) who tested nine flatwater kayak paddlers (competing in 1000 m events) on an arm crank ergometer with modified handlebars to simulate the paddling action. Subjects ( $n = 9$ ) completed a continuous incremental protocol (2 min increments of 50 W) to exhaustion to determine power output at  $\text{VO}_{2\text{max}}$ . One week later, subjects completed a “time to exhaustion” test at a fixed power output (the power output at  $\text{VO}_{2\text{max}}$ ) (mean:  $239 \pm 56$  W). The group mean for “time to exhaustion” was  $376 \pm 134$  s. The aim of this study was to compare the “times to exhaustion” at a fixed workload of paddlers to that of cyclists, runners and swimmers.

Kayak performances and their predictors in a laboratory setting have been investigated for sprint performance but not endurance performance. Bishop (2000) investigated the physiological predictors of 500 m kayak performance by means of a 2 min all-out performance test on the K1 Ergo in female high-performance kayak paddlers ( $n = 9$ ). A 2 min sprint test on the ergometer approximates the time of a 500 m performance on water. Bishop (2000) found no significant correlation between average work (Watt) during the 2 min sprint test and the 500 m race time ( $r = 0.61$ ,  $P > 0.05$ ). On the other hand, Van Someren & Palmer (2003) investigated the relationship between 200 m performance time and a 30 s supramaximal sprint on the K1 Ergo in experienced male kayak paddlers ( $n = 26$ ).

They found significant correlations between peak work and total work during the 30 s sprint test, and the 200 m race time ( $r = -0.69$  and  $r = -0.73$ ,  $P < 0.05$ ). A possible explanation for the contradictory results from these two studies is the sample size. The study of Bishop (2000) included just nine paddlers and it can be hypothesized the correlation between average power during the 2 min test and the 500 m race time could have been significant if a larger sample size was chosen.

In studies investigating the effects of an intervention on performance, kayak sprint performance tests of various durations (a few seconds to 300 s) have been utilized. Aitken & Jenkins (1998) studied the effect of a 12 wk kayak training programme on a 2 min kayak ergometer sprint test in school children. Both boys and girls significantly improved their total amount of work done (kJ) on the kayak ergometer after training (33% and 42%, respectively;  $P < 0.05$ ). McNaughton et al. (1998) studied the effect of a five-day creatine supplementation period on 90, 150 and 300 s maximal performance on a wind-braked kayak ergometer. The supplementation group completed significantly more work than the placebo group during all three sprint tests (90 s,  $P < 0.01$ ; 150 s,  $P < 0.001$ ; 300 s,  $P < 0.05$ ). Liow & Hopkins (2003) compared slow weight training with explosive weight training (four-week intervention) and the different effects these training methods had on 15 m kayak sprint performance, in an indoor swimming pool, in experienced male and female sprint kayakers ( $n = 38$ ). The two training programmes differed only in the time it took to complete the concentric phase of the muscle contraction (1.7 s for slow and  $< 0.85$  s for explosive training). The 15 m sprint performance time was improved by 3.4% in the slow weight training group and 2.3% in the explosive weight training group and decreased with 0.2% in the controls. The study did not report whether these improvements were statistically significant among the three groups. The percentage difference in the improvements in sprint performance (90% confidence limits in brackets) between the slow weight training and the control group was  $3.6 \pm 1.6\%$  (99.9). The difference between the explosive weight training group and the control group was  $2.5 \pm 1.2\%$  (99.5) and between the slow and explosive weight training group were  $1.1 \pm 1.4\%$  (74).

The reliability and validity of kayak sprint performance tests on the K1 Ergo have been reported. Van Someren & Dunbar (1997) showed a test-retest correlation coefficient of  $r = 0.99$  ( $P < 0.01$ ) for peak power during a 30 s supramaximal performance test. Van Someren et al. (2000) reported the validity of a 4 min self-paced performance trial on the K1

Ergo. The work done during the 4 min laboratory kayak simulation showed a strong relationship with the maximum distance (m) covered during a 4 min time trial on open water ( $R^2 = 0.86$ , SEE = 18.75 m). These studies therefore show that short duration kayak performance tests are both reliable and valid methods to assess sprint performance in the laboratory.

All of the above studies involved kayak sprint performance tests. The use of kayak endurance performance tests as valid and reliable tests has not yet been investigated.

### **3. Kayak endurance performance tests on open water**

Despite the shortcomings in the literature on the physiological assessment of kayak performance in the laboratory, kayak endurance performance events on open water, and the physiological and kinanthropometric attributes which best predict performance of longer duration, have been investigated previously.

Tesch et al. (1976) investigated the  $\text{VO}_2$  responses in six Swedish elite canoeists (4 seniors, 2 juniors) over three different racing distances (500 m, 1000 m and 10 000 m) on open water and over 2 min, 4 min and 45 min in an indoor pool. The average  $\text{VO}_2$  uptakes during the 500 m, 1000 m and 10 000 m open water races were 4.2, 4.7 and 4.5  $\text{L} \cdot \text{min}^{-1}$ , respectively, while average  $\text{VO}_2$  uptakes during the 2 min, 4 min and 45 min exercise bouts in the pool were 3.3, 4.1 and 3.1  $\text{L} \cdot \text{min}^{-1}$ , respectively. They did not report any differences in  $\text{VO}_2$  uptakes between the different distances or between the open water races and exercise bouts in an indoor pool. They suggested that the physiological demands for the 3 different racing distances are not very different. They suggested that both aerobic and anaerobic energy sources are equally important for all three distances. This finding of Tesch et al. (1976) could be questioned, since it is contradictory to the general belief that the physiological demands for sprint events (500 m and 1000 m) differ from these for endurance events (10 000 m).

In contrast to this study, Tesch & Karlsson (1984) obtained muscle biopsies before and after a 2 min and a 45 min simulated kayak performance in an indoor pool in five elite Swedish canoeists (3 seniors, 2 juniors). There was a significant increase in the concentrations of glucose ( $P < 0.001$ ), glucose-6-phosphate ( $P < 0.05$ ) and lactate ( $P < 0.01$ ) and a significant

decrease in creatine phosphate ( $P < 0.05$ ) and glycogen ( $P < 0.01$ ) after the 2 min work bout. There was no significant elevation in glucose, but a significant decrease in glycogen ( $P < 0.01$ ) after the 45 min work bout. They concluded that the metabolic demands for events lasting 2 min (500 m races) differ from events lasting 45 min (10 000 m races). They suggested that anaerobic energy production is of greater importance during short distance events. A possible reason for the different outcome in this study than in the study of 1976, is that the investigation into energy demands through muscle biopsies, rather than  $\text{VO}_2$  kinetics, gave a clearer indication that energy contribution from glycolytic precursors and the anaerobic component is of greater importance in short distances than in exercise of long duration.

Pickard & Pyke (1981) recorded the times for 1000 m and 10 000 m races in surf-ski paddlers and they correlated these times with the variables measured during an incremental test on a kayak ergometer. Multiple regression analysis showed that  $\text{VO}_{2\text{max}}$  accounted for 42% and 50% of variation in performance in the 1000 m and the 10 000 m race times, respectively. Anaerobic threshold contributed to 7% of the variation in performance in the 10 000 m race and showed no contribution to variation in performance in the 1000 m race. All other variables tested in the laboratory (isometric and isokinetic strength tests) during this study did not contribute to the variation in performance in either of the two events. Thus, other physiological factors not measured during this study, or external factors that are difficult to measure, are responsible for the remaining variance in paddling performance. The greater contribution of  $\text{VO}_{2\text{max}}$  and anaerobic threshold to the 10 000 m event compared to the 1000 m event shows the importance of the aerobic energy system in longer events.

In support of the abovementioned study with regard to the physiological attributes which best predict kayak endurance performance, Fry & Morton (1991) examined the physiological attributes of paddlers and correlated all the variables with a 42 km race time. The best predictor of the 42 km race time was the time to exhaustion during the incremental test on the modified paddling ergometer ( $r = -0.84, P < 0.05$ ). This was followed by  $\text{VO}_{2\text{max}}$  as the second best predictor ( $r = -0.80, P < 0.05$ ). Strength tests conducted on a Cybex II isokinetic dynamometer (simulating the same range of movement as during the paddling action) correlated significantly with the 42 km race time ( $r = -0.69, P < 0.05$ ). They concluded that aerobic capacity, time to exhaustion and muscular strength are important contributors to performance over marathon distance.

A third study which also investigated the predictors of kayak endurance performance was Olivier & Coetzee (2002) correlated arm span, grip strength, sit-and-reach test, arm dips and VO<sub>2</sub> peak (measured during incremental testing on an arm crank ergometer) with a 7 km time trial on open water. Significant correlations were found between relative VO<sub>2</sub> peak ( $r = -0.81$ ) and the 7 km race time. Significant, but low correlations were found between sit and reach ( $r = -0.44$ ) and arm dips ( $r = -0.58$ ) and the 7 km race time ( $P < 0.01$ ). They suggested that maximum aerobic capacity, flexibility and arm strength are important contributors to 7 km endurance performance, but that arm span and grip strength are not.

#### **4. Possible implications of kayak endurance performance tests**

Laboratory based cycle time trial performance tests are recognized as reliable methods to assess endurance performance, where all other external factors, e.g. competitors performance and the athletes's relative standing in the event, that can possibly influence performance, are properly controlled. Hickey et al. (1992) reported that while these external factors are properly controlled, trained cyclists are able to reproduce their time trial performance in the laboratory, but it is still unknown whether these outside factors will alter time trial performance and if they do, the need exists to quantify to what extent.

Olivier & Coetzee (2002) suggested that paddling is a multi-skilled activity. They mentioned that it requires balance and technical ability, including an ability to "read" waterflow on the river. Balance and technical skills are therefore additional external factors that will influence performance.

#### **5. Conclusion**

The evaluation of kayak sprint performance tests in the laboratory has been thoroughly investigated, but no study has investigated the evaluation of kayak endurance performance in a laboratory setting. However, the physiological demands of kayak endurance performance and the predictors thereof have been thoroughly investigated on open water. Thus, the need exists for the development of a standardized kayak endurance performance test in the laboratory.

Endurance kayaking is a multi-skilled activity with a variety of external factors that can possibly influence performance on water. Endurance performance tests should be highly valid and reliable in order to accurately conclude that changes in endurance performance are caused by biological adaptations only, and not by external factors such as motivation, competition, or technical changes. From previous investigations it is suggested that time trial endurance performance tests represent a viable alternative to the administration of endurance performance as opposed to the unusual “time to exhaustion” endurance capacity tests. Kayak endurance performance testing should accurately simulate competition conditions.

## **CHAPTER FOUR**

### **CORE STABILITY**

#### **A. INTRODUCTION**

Anatomically, the core of the body consists of the lumbar spine, the pelvis and the surrounding muscles which stabilize or support the lumbar spine and the pelvis during movement of the limbs and the trunk (Marlow, 2001).

These surrounding muscles are the deep trunk muscles and include the *Transversus Abdominis*, *Multifidus*, internal oblique, paraspinal and pelvic floor muscles. The co-contraction of these muscles produce forces to stabilize the lumbar spine and the pelvis, while the paraspinal and *Multifidus* muscles directly resist the forces acting on the lumbar spine. Hodges & Richardson (1996) showed that the co-contraction of the *Transversus Abdominis* and *Multifidus* muscles occurred prior to any movement of the limbs. This suggests that these muscles anticipate dynamic forces that may act on the lumbar spine and stabilize the area prior to any movement.

#### **B. CLAIMED BENEFITS OF CORE STABILITY TRAINING**

It is claimed that the benefits of core stability training are applicable to all sports where qualities such as agility, balance and co-ordination are vital to succeed. Firstly, coaches and fitness experts claim that the main benefit of core stability training is the elimination of inappropriate loading at the joints. Inappropriate loading at the joints due to poor posture and poor control over movements are the major cause of injury. Thus better core stability reduces the incidence of injury (Marlow, 2001).

Secondly, coaches also claim that increased stability of the pelvis and the spine improves body control or balance during athletic movements. This allows the athlete to generate greater power, not just from the core, but also from the shoulder, arm and leg muscles because they are anchored to the core.

Thirdly, it is claimed that the athlete will become more efficient in his/her movements, since better core stability will ensure the optimal transfer of energy from the core to the extremities while the athlete runs, jumps, twists, lifts, throws or withstand a tackle (contact sports).

Other claimed benefits of core stability training include a greater capacity to generate speed and an improvement of the control over body momentum, which in turn will improve the ability to quickly and effectively change direction (agility). It will also improve muscular co-ordination and improve body posture.

None of these proposed effects of core stability training has been scientifically investigated.

### **C. STABILITY REQUIREMENTS FOR KAYAKING**

In kayaking, it is hypothesized that core stability is of greater importance compared to other sports performed on land (stable environment), since additional demands are placed on the stabilizing muscles to provide adequate balance of the paddler in the kayak on the water (unstable environment).

During the paddling action, the paddler needs to simultaneously perform alternated circular movements with his/her arms, rotation of his/her trunk and pushing movements with his/her legs, while remaining stable in the kayak. Good core stability ensures that the working joints only move through the necessary range of motion to execute the perfect paddling stroke, while the movement in all the other joints is minimized to prevent energy waste or “power leaks”. Therefore, a stable core could provide a more stable base against which the muscles can work, resulting in a more efficient paddling stroke. Strong core muscles could also provide a strong base from where the paddling action starts, resulting in a more powerful stroke.

No available studies in the literature investigated the importance of core stability or balance in paddlers. A few studies have mentioned that balance could play an important role in kayak performance. Pickard & Pyke (1981) reported that only 57 % of the variance in a 10 km race could be explained by their laboratory tests. They suggested that the remaining unexplained 43 % of variance in paddling performance must be attributed to other factors not

measured in their laboratory profile. They suggested that one of these factors could have been the efficiency of on-water paddling. Olivier & Coetzee (2002) also reported that 24 % of the variance in a 7 km race could not be explained by their laboratory and field tests. They suggested that paddling is a multi-skilled activity that includes balance as one of the important skills. Bishop (2000) found no significant correlation between the variables measured during a 2 min K1 Ergo test and a 500 m performance time. He suggested that the stability of the paddlers could have been one of the factors that influence performance on the water, which is less the case during performance testing on the K1 Ergo.

#### **D. QUANTIFICATION OF CORE STABILITY**

Currently there is no practical method for the assessment of core stability. This is probably the reason why available research is lacking in studies supporting the proposed benefits of core stability training. Electromyographic (EMG) activity, using finewire or surface electrodes, has been measured to investigate the role of the trunk muscles in the prevention and rehabilitation of lower back pain (Hodges, 1999). Other studies have also measured intra-abdominal pressure to investigate the different loads applied to the trunk for preventative and rehabilitation purposes (Grew, 1980).

In research, the invasive procedures to measure EMG activity and intra-abdominal pressure are time consuming, expensive and require great expertise. An attempt was made by Moreland et al. (1997) to investigate practical, non-invasive methods to evaluate the strength and endurance of the trunk muscles in a clinical setting. They tested the interrater reliability of six trunk muscle strength and endurance tests. They found acceptable interrater reliability coefficients for the abdominal dynamic endurance ( $ICC = 0.89$ ) and extensor dynamic endurance ( $ICC = 0.78$ ) tests, but not for the abdominal ( $ICC = 0.25$ ) and extensor ( $ICC = 0.24$ ) isometric force tests or the abdominal ( $ICC = 0.51$ ) and extensor ( $ICC = 0.59$ ) static endurance tests. They suggested that the dynamic endurance tests could help identify the risk factors and prognostic indicators for lower back injuries. However, neither these tests, nor EMG activity or intra-abdominal pressure actually quantify core stability. In other words, it does not measure the ability of the individual to stabilize himself in an unstable environment. In order to test core stability an individual's proprioception must be put to the test.

Proprioception is the awareness of the body's position in space. The central nervous system receives information from specialized nerve endings located in the skin, muscles, tendons, joint capsules and ligaments. As a result, spinal reflexes send messages to the muscles to react and protect the body from external forces. Thus, proprioception is an action-reaction mechanism to protect the body (Kruger et al., 2004). If the body is put in an unstable environment, proprioceptive sensory nerve endings send messages to the central nervous system (action). In return, spinal reflexes send messages to the stabilizing muscles to contract in such a way to maintain balance and keep body position in equilibrium (reaction). Thus, in this situation the strength and endurance of the stabilizing muscles, together with the individual's skill to balance him/herself, is used.

No standardized practical method to test core stability exists in the literature. In this study, six existing core stability exercises were modified and combined into a proposed core stability test battery. This test battery was used as the method for measurement of core stability.

## **CHAPTER FIVE**

### **RESPIRATORY MUSCLE FUNCTION**

#### **A. INTRODUCTION**

RM fatigue during exercise can possibly be explained by the hypothesis of Dempsey (1986). He hypothesized that in untrained individuals the capacity for oxygen transport by the pulmonary system far exceeds that of the cardiovascular system and the oxidative capacity of the working limb muscles. Physical training, however, causes adaptations in skeletal muscles and in the systemic cardiovascular system to transport and utilize oxygen during exercise, with little change in the pulmonary system. Therefore, in well-trained individuals the capacity of the pulmonary system for oxygen transport cannot meet the superior demands imposed by the limbs and cardiovascular system, which leads to fatigue of the respiratory system prior to, or simultaneously with the fatigue of the other two systems.

In some studies RM fatigue was induced prior to exercise performance to investigate the effect of RM fatigue on exercise performance. Some researchers reported a reduction in performance (Martin & Stager, 1981; Mador & Acevedo, 1991), while others reported no alteration in performance (Marciniuk et al., 1994).

Another method of investigating the effect of RM function on exercise performance is through RM training. More recently, with the invention of RM trainers (breathing against a resistive load), the effect of specific RM training upon exercise performance has been investigated. Some studies reported that an improvement in RM function led to an improvement in performance after an intervention period of specific RM training (Volianitis et al., 2001; Romer et al., 2002). Other studies reported an improvement in RM function after a RM training intervention, but no improvements in exercise performance (Morgan et al., 1987; Fairbarn et al., 1991; Williams et al., 2002).

#### **B. RESPIRATORY MUSCLES AND THEIR FUNCTION DURING EXERCISE**

Originally, the assessment and interpretation of RM function was investigated to diagnose RM weakness in patients with lung pathology. However, with the constant challenges

placed upon sport scientists and exercise physiologists to determine those factors that limit superior athletic performance, the investigation into the role of RM function during exercise in healthy individuals, has become more apparent.

To fully understand the possibility of RM fatigue during exercise the function of the RM and the demands placed upon them during exercise must be explained.

## **1. The respiratory muscles**

The RM can be classified as primary and accessory muscles of ventilation. During quiet breathing, inspiratory muscles are active during inspiration, while expiration is passive and achieved via the elastic recoil of the lung and the chest wall. When the inspiratory muscles contract, the chest cavity expands and alveolar pressure becomes subatmospheric. This induces airflow into the lungs (Sheel, 2002).

During quiet breathing, the diaphragm mainly contributes to the active inspiratory volume change, while the intercostal muscles are slightly active, keeping the ribs in a constant position so as to not extend the thorax too much. They become more active during heavy ventilatory demand (i.e. exercise). In healthy individuals, the accessory inspiratory muscles only become active during heavy ventilatory demand (Beachey, 1998).

EMG activity recordings showed that the diaphragm is recruited in proportion to increasing exercise hyperpnoea as exercise intensity increases. As exercise proceeds the diaphragm contributes less and less to the total pressure generated by the inspiratory muscles and the accessory muscles contribute more and more to the total pressure generated by the inspiratory muscles (Sheel, 2002). The most important accessory muscles for expiration are the abdominal muscles i.e. *Rectus Abdominis*, internal and external obliques and the *Transversus Abdominis*. They become actively involved in expiration during exercise and in a proportional manner as exercise intensity increases (Sheel, 2002).

## **2. The energy demands of the respiratory muscles**

The energy demands for locomotor muscle contractions increase as exercise intensity increases to maintain a higher work rate. The same happens with the energy demands for

respiratory muscle contraction since the respiratory muscles have to work harder to maintain the high level of ventilation during exercise. The factors determining the energy demands of the respiratory muscles during exercise is the work of breathing, the strength of the inspiratory muscles and their efficiency. Any factor that causes an increase in the work of breathing, such as hyperventilation during exercise, increases the demand for energy. Stronger and more efficient respiratory muscles need less energy and therefore less oxygen at a given level of exercise intensity compared to weaker and inefficient respiratory muscles (Macklem, 1980).

The blood flow to the respiratory muscles must be sufficient to meet the high energy demands of the respiratory muscles. During exercise the cardiac output is divided between the respiratory muscles and the working muscles to meet their energy demands for ventilation and exercise, respectively. Aaron et al. (1992) reported that the oxygen cost of breathing is approximately 2% and 3 – 5% of total body oxygen consumption during rest and moderate exercise, respectively. The oxygen cost of hyperventilation during heavy exercise amounted to 10% of the  $\text{VO}_{2\text{max}}$  achieved in untrained individuals and up to 15 – 16% of the  $\text{VO}_{2\text{max}}$  in fit individuals. They concluded that the oxygen cost of exercise hyperpnoea is a significant fraction of the total  $\text{VO}_{2\text{max}}$ .

### **3. The assessment of respiratory muscle function**

Various invasive and non-invasive methods exist to assess respiratory muscle function. Invasive procedures include the study of electromyographic (EMG) activity of the diaphragm muscle and changes in transdiaphragmatic pressure (Pdi) response to supramaximal phrenic nerve stimulation (Laporta & Grassino, 1985; Babcock et al., 1995; Johnson et al., 1992). These complicated and invasive procedures are not feasible for routine exercise testing of athletes, and therefore will not be discussed further. Instead the more practical, non-invasive methods, i.e. pulmonary function and maximum inspiratory mouth pressure (MIP) to assess respiratory muscle function are briefly explained.

In exercise physiology the FVC maneuver (FVC, FEV<sub>1</sub>, PEF) is used to assess respiratory muscle function and lung capacity, while MVV tests are used to assess the RM endurance of athletes.

### **3.1 Pulmonary function**

Dynamic pulmonary function is measured to determine lung volume, the ability of the lungs to move air rapidly in and out of the lungs (Beachey, 1998). It is also an indirect measurement of RM strength (forced vital capacity [FVC] maneuver) and RM endurance (maximum voluntary ventilation [MVV]). Factors that determine lung volume include stature, age, gender, body mass, posture, ethnic group and the amount of daily activity (Quanjer et al., 1993).

#### **Volume measurements over time:**

- i) *Forced vital capacity (FVC):* FVC is the maximum volume of air that a person can exhale as forcefully and rapidly as possible after a maximum inspiration up to total lung capacity (TLC). The FVC maneuver is effort-dependent.
- ii) *Forced expiratory volume in 1 second (FEV<sub>1</sub>):* This is the volume of FVC exhaled in 1 second. Because FEV<sub>1</sub> is measured over time, it reflects the average flow rate over its time interval.
- iii) *Peak expiratory flow rate (PEF or PEFR):* PEF is the highest instantaneous flow achieved during the FVC maneuver. The PEF reflects initial flows coming from large airways at the beginning of the FVC maneuver. The PEF is also effort-dependent which reflects whether the subject gave a maximal effort during the FVC maneuver or not. This value is, amongst others, used in the evaluation of the response to bronchodilator drugs.
- iv) *Maximum voluntary ventilation (MVV):* This is the greatest volume of air that a person can move in and out of his/her lungs with maximal effort over 10 to 15 s. Results are expressed in litres per minute. MVV reflects RM endurance, airway function, lung compliance and neural control mechanisms (Beachy, 1998).

**The effect of physical training:** Many investigators reported that athletes have larger lung volumes and capacities compared to sedentary individuals (Kaufmann et al., 1974; Pherwani et al., 1989; Lakhera et al., 1994), while others found no significant differences in lung volumes and capacities between athletes and non-athletes (Grimby & Saltin, 1971; Shapiro et al., 1964). These contradictory results of different studies imply that an agreement as to whether physical training causes an improvement in lung volume and capacities, has not yet been reached.

Bertholon et al. (1986) reported that a group of rowers had significantly higher vital capacity (VC), PEF and FEV<sub>1</sub> values than a control group of 20 healthy sedentary individuals. Lakhera et al. (1994) found significant differences in FEV<sub>1</sub> ( $P < 0.05$ ) and MVV ( $P < 0.001$ ) between adolescent athletes and non-athletes of the same age, height and body mass. Robinson & Kjeldgaard (1982) reported a significant increase in MVV (13.6%) and maximum sustained ventilatory capacity (MSVC) for 15 min (15.8%) following a 20 week running training programme in 11 healthy volunteers ( $P < 0.001$ ). The control group showed no changes in any of the tests after 20 weeks. They suggested that running could improve ventilatory muscle strength and endurance in healthy, previously sedentary individuals. Shapiro et al. (1964) found no significant differences in lung function between highly trained athletes ( $n = 7$ ) and non-athletes ( $n = 5$ ) ( $P > 0.05$ ), although subject numbers were low.

**Reproducibility:** Romer & McConnell (2003) assessed pulmonary function and MVV measurements in 46 healthy, physically active individuals on two separate occasions. Measurements were repeated within at least two days and no longer than three weeks later. They found no significant differences in MVV ( $187 \pm 28$  vs  $188 \pm 27$  L·min<sup>-1</sup>,  $P > 0.05$ ) between the baseline and repeated measurements. However, they found significant differences between the test-retest measurements for FVC ( $5.66 \pm 0.66$  vs  $5.71 \pm 0.61$  L,  $P < 0.01$ ) and PEF ( $10.3 \pm 1.3$  vs  $10.6 \pm 1.3$  L·s<sup>-1</sup>,  $P < 0.05$ ). This suggests a poor reproducibility of the latter two measurements. A possible explanation for the significant differences is that these measurements are greatly effort-dependent and it could have been that the subjects were more motivated during the second measurement or there could have been a learning effect. Nevertheless, 95% ratio limits of agreement for these measures according to Bland & Altman (1986) were calculated and proved to be acceptable. The random error component of the agreement ratios was 1.047 and 1.149 for FVC and PEF, respectively.

### 3.2 Maximum inspiratory mouth pressure (MIP)

MIP can be defined as the static pressure measured at the mouth during a maximal inspiratory effort from residual volume. MIP is the indirect assessment of the inspiratory muscle strength.

Factors determining MIP: Unlike pulmonary function measurements, the association between age, physical characteristics, and MIP are still inconclusive. Some studies reported that MIP declines as age advances (Black & Hyatt, 1969; Wilson et al., 1984; Karvonen et al., 1994; McConnell & Copestake, 1999), while other studies only reported weak associations between age and MIP (McElvaney et al., 1989; Bruschi et al., 1992). Wilson et al. (1984) correlated height with MIP in healthy men, women, boys and girls, but only found a significant correlation in women ( $P = 0.04$ ).

Very little research exists on the relationship between physical activity and MIP measurements. McConnell & Copestake (1999) investigated the influence of physical activity on MIP measurements in healthy elderly individuals ( $n = 41$ ). The subjects were required to keep a diary record card over a period of four weeks and record all physical activities greater than 20 min duration. They found a significant correlation ( $r = 0.87$ ,  $P < 0.001$ ) between physical activity and MIP measurements. They suggested that the influence of different levels of physical activity make the interpretation of normal values of MIP problematic. But in contradiction to these findings, Coast et al. (1990) found no significant differences in the baseline MIP of highly trained cross country skiers ( $n = 6$ ) and sedentary college students ( $n = 5$ ) ( $116 \pm 5.7$  vs  $101 \pm 11.1$  mmHg,  $P > 0.05$ ), although the sample size was small.

Due to these inconclusive and contradictory outcomes more investigations into the relationships between age, physical characteristics, physical activity, and MIP measurements are needed to accurately determine which factors are responsible for MIP differences among individuals.

Reproducibility: McConnell & Copestake (1999) reported no significant differences between the first and second MIP measurements ( $94 \pm 25.9$  vs  $97 \pm 26.3$  cmH<sub>2</sub>O,  $P > 0.05$ ) taken one week apart in a group of healthy elderly individuals ( $n = 41$ ). They reported that the coefficient of reproducibility for MIP was acceptable with 95% of the subjects generating retest pressures within 11% of the initial reading.

Maillard et al. (1998) measured MIP one day and one month after baseline measurements in ten healthy individuals. The between-occasion reproducibility of the MIP measurements was assessed between the baseline and one day later measurements (session 1 and 2) and

between the one day after and one month after measurements (session 2 and 3). The mean and SD of differences between sessions were calculated, and the coefficient of repeatability was computed as twice the SD. The coefficient of repeatability of MIP was 28 and 21 cmH<sub>2</sub>O between session 1 and 2, and 2 and 3, respectively. They suggested that reproducibility was not deteriorating over time, since coefficient of repeatability was lower after one month than after one day.

Volianitis et al. (1999) reported no statistically significant differences between two baseline MIP measurements in eleven club level rowers. The mean difference was less than 5 cmH<sub>2</sub>O ( $P > 0.05$ ). The mean ( $\pm$  SE) coefficient of variation for the baseline MIP measured on the two occasions was 4.65 ( $\pm$  0.76)%.

### C. RESPIRATORY MUSCLE FATIGUE

The respiratory muscles form a vital pump, similar to the heart, in the oxygen transport system to supply the working muscles with sufficient oxygen during exercise (Macklem, 1980). It is believed that skeletal muscles will reach a point of maximum sustained work output during exercise of increasing intensity and that thereafter; they will fail to produce the predetermined amount of work. This denotes the development of muscle fatigue. Similarly, it is suggested that the inspiratory muscles also reach a maximal capacity to produce sufficient ventilation and gas exchange during exercise of increasing intensity. Thus, if exercise intensity increases even more, the respiratory muscles will fail to increase their capacity to contract, or may not be able to maintain this capacity, and this will result in RM fatigue. Fatigue can be defined as the inability to develop or maintain a predetermined force (work).

#### 1. Evidence of respiratory muscle fatigue

Various studies have shown evidence of RM fatigue during or after exercise. Loke et al. (1982) observed a significant decrease in MIP ( $166 \pm 11$  vs  $139 \pm 8$  cmH<sub>2</sub>O,  $P < 0.05$ ) and a significant decrease in maximum expiratory mouth pressure (MEP) ( $P < 0.05$ ) and MVV ( $P < 0.005$ ) after a 42.2 km race in well-trained runners. They suggested that these decrements in RM strength (MIP and MEP) and RM endurance (MVV) indicated the development of RM fatigue. More recently, Romer et al. (2002) observed a significant

decrease in MIP (18% and 13%,  $P < 0.01$ ) two minutes after a 20 km and 40 km cycling time trial (TT), respectively. They concluded that inspiratory muscle fatigue occurred during sustained heavy endurance exercise in trained competitive cyclists.

Bye et al. (1984) observed a decline in the frequency of EMG signals (20%) and a significant decrease in transdiaphragmatic pressure (Pdi) ( $P < 0.05$ ) after a cycling test to exhaustion (80% of maximum workload on a cycle ergometer) in moderately active men. They concluded that diaphragmatic fatigue occurs during short-term high-intensity exercise. McConnell et al. (1997) observed a significant fall in MIP after an incremental, multi-stage shuttle run to volitional fatigue (8.2%,  $P < 0.001$ ) in moderately trained males. They suggested that their findings support existing evidence that RM fatigue is a result of high intensity exercise.

From the abovementioned studies it is clear that RM fatigue occurs during short-term, high-intensity exercise and during long-term endurance exercise. These findings are observed in highly trained competitive athletes and in moderately active individuals.

## **2. Effects on athletic performance**

The relationship between respiratory fatigue and athletic performance has been studied under different conditions, namely, the partial unloading of respiratory muscles, induced RM fatigue and the effects of RM training.

*Partial unloading of RM work:* Harms et al. (2000) assessed the effect of high level RM work on athletic performance during a control and unloaded RM work conditions. Unloading of RM work implies that the work of inspiration by the inspiratory muscles is assisted with a mechanical ventilator. “Unloading” increased cycling time to exhaustion (90%  $\text{VO}_{2\text{max}}$  and higher) by  $14 \pm 5\%$  compared to control conditions in highly trained cyclists ( $P < 0.05$ ). This finding suggests that a reduction in the work of the respiratory muscles leads to a significant increase in performance. Therefore, it indirectly suggests that increased RM work will influence performance negatively.

*RM fatigue prior to exercise:* Mador & Acevedo (1991) induced RM fatigue in ten healthy individuals to determine whether it will impair subsequent exercise performance. RM

fatigue was established by having subjects breathe against a resistive load (80% of MIP) until they could not sustain the predetermined target pressure. After induction of RM fatigue, exercise time to exhaustion (at 90% of the maximum workload achieved during incremental test on cycle ergometer) decreased with 23% in healthy individuals ( $P < 0.001$ ). From the results of this study it can be suggested that if RM fatigue occurs during exercise, it will subsequently impair exercise performance.

*RM training:* Romer et al. (2002) investigated the effect of a 6-week RM training programme on a 20 km and 40 km cycling TT in competitive male cyclists (n=16). There was a  $3.8 \pm 1.7\%$  and  $4.6 \pm 1.9\%$  significant improvement in the 20 km and 40 km TT after the six week intervention ( $P < 0.05$ ).

They explained that the mechanism by which RM training improves performance is still unclear. Romer et al. (2002) suggested that RM training improves the endurance of the respiratory muscles, which leads to a delay in the recruitment of the accessory muscles during heavy ventilation. This improved efficiency of the respiratory muscles leads to an improved efficiency of breathing during heavy exercise. More efficient breathing causes a reduction in metabolic and blood flow demands by the respiratory muscles. Romer et al. (2002) also suggested that if the respiratory muscles require less blood flow there will be an increase in blood flow to the working skeletal muscles, since the respiratory muscles and the skeletal muscles share the majority of cardiac output during exercise. Improved blood flow to the skeletal muscles will better meet the energy demands of these muscles and will delay the onset of fatigue in the skeletal muscles.

A reduction in the work of the respiratory muscles will also lead to a decrease in the subject's perception of breathing effort (dyspnoea) during exercise. A reduction in dyspnoea will make it less likely that the subject will voluntarily cease exercise because of dyspnoea.

### **3. Practical problems**

Both, the incidence of RM fatigue during exercise and its effect on athletic performance are still controversial issues, as some researchers reported no RM fatigue during maximal exercise (Coast et al., 1990; Nava et al., 1992); some reported no effect of RM fatigue upon subsequent exercise performance (Marciniuk et al., 1994); and some reported no

improvement in exercise performance following a specific RM training programme (Williams et al., 2002).

The major reasons for the different outcomes of the various studies can be attributed to the differences in the laboratory tests to measure exercise performance, differences in the training status of the individuals tested, and differences in the assessment methods of RM function.

*Differences in laboratory tests:* Studies involving the effect of RM function on performance that used different exercise protocols, showed different effects on performance. As previously discussed in Chapter 3, the most commonly used laboratory test of performance is exercise time to exhaustion at a fixed work rate. This test is, however, not true measures of athletic performance because they do not mimic real competition situations. Williams et al. (2002) used an incremental  $\text{VO}_{2\text{max}}$  protocol and running to exhaustion at 85% of  $\text{VO}_{2\text{max}}$  as measurements of performance and found no significant alteration in these exercise tests after a four-week RM training programme. In contrast to this study Volianitis et al. (2001) used a 5 000 m rowing TT and Romer et al. (2002) used a 20 km and 40 km cycling TT to measure performance, respectively. They both found significant improvements after RM training.

It seems that studies where fixed workload protocols were used to investigate the occurrence of RM fatigue or to determine the effect of RM training on performance, generally reported negative results. However, the significance of these studies for specific sports is questionable since this is not the manner in which athletes train or compete.

*Differences in training status of individuals:* Coast et al. (1990) found RM fatigue after maximal exercise in sedentary individuals ( $n = 5$ ) (10 – 17% decrease in MIP,  $P < 0.05$ ) but not in highly trained cross-country skiers ( $n = 6$ ). They suggested that the highly-trained skiers already had superior RM strength and endurance and were not susceptible to fatigue during maximal exercise. Widespread evidence in the literature (Martin & Chen, 1982; Nava et al., 1992; McConnell & Copestake, 1999) suggests that physical (whole-body) training results in improved RM strength and endurance.

It would be logical to assume that if the respiratory muscles are exposed to prolonged periods of hyperventilation (as during regular training) it will cause aerobic adaptations in

the respiratory muscles, similar to the adaptations in the limb muscles when exposed to prolonged periods of repetitive endurance exercise. Therefore, researchers suggest that when RM fatigue is assessed, the specific group of individuals tested must possess very similar training status.

#### **D. RESPIRATORY MUSCLE FUNCTION AND UPPER BODY EXERCISE**

Very few studies exist on RM function and athletes typically doing arm exercise. Of the available studies, Bertholon et al. (1986) showed that kayakers had significantly higher PEF and FEV<sub>1</sub> than sedentary individuals ( $P < 0.01$ ). In the same study, rowers showed significantly higher PEF, FEV<sub>1</sub> and vital capacity (VC) compared to the same sedentary individuals ( $P < 0.01$ ). These findings showed that athletes participating in sports involving predominantly arm exercise (rowing and kayaking) have greater lung volumes and capacities than non-athletes. This is probably brought about as a result of regular arm exercise during training.

Volianitis et al. (2001) stated that additional demands are placed on the respiratory muscles during rowing. These additional demands include stabilization of the thorax during the rowing stroke and the entrainment (locomotion-breathing coupling) during rowing. They suggested that the additional work done by the respiratory muscles may play an important role in the development of RM fatigue during rowing. Although this scenario has been suggested before, no study has investigated it yet.

In rowing, RM fatigue was found after a 6 min all-out rowing performance in trained rowers (11.2% reduction in MIP,  $P < 0.05$ ). An 11-week RM training programme significantly improved a 5000 m rowing TT ( $3.1 \pm 1.8\%$  decrease in time,  $P < 0.05$ ) and the 6 min all-out rowing effort ( $3.5 \pm 1.2\%$  increase in distance,  $P < 0.05$ ). This study confirms that RM fatigue occurs during rowing performance and that RM function has an effect on rowing performance (Voliantis et al., 2001)

It would be logical to postulate that the additional demands placed on the respiratory muscles during rowing are also applicable to kayaking. However, no study has reported the incidence of entrainment of breathing during the kayak stroke or the use of the respiratory

muscles to stabilize the thorax. The incidence of RM fatigue during kayak performance has also not yet been investigated.

A few studies have reported that elite paddlers have superior lung volumes and capacities compared to less successful paddlers, other athletes and non-athletes (Fry & Morton, 1991; Misigoj-Durakovic & Heimer, 1992; Van Someren & Palmer, 2003). Some studies have investigated the relationship between lung capacities and performance, but with contradictory outcomes. Fry & Morton (1991) found a significant correlation between FVC and a 42 km kayak event ( $r = -0.70$ ,  $P < 0.05$ ) in competitive male paddlers ( $n = 38$ ). Van Someren & Palmer (2003) found no significant relationship between FVC ( $r = -0.06$ ), FEV<sub>1</sub> ( $r = 0.02$ ), PEF ( $r = -0.13$ ) and a 200 m kayak race performance. Although the researchers gave no possible explanation for their findings, one may speculate that the reason for the contradictory outcomes in the correlations of lung volumes and flows with performance is that aerobic endurance plays a more important role in the 42 km race (long distance) than in the 200 m race (sprint distance). This indirectly reflects that the capacity of the oxygen transport system (of which lung volumes are part) is an important predictor of prolonged endurance performance, but is of less importance in short, sprint performance.

Due to the additional role of the respiratory muscles during rhythmic arm exercise (e.g. rowing and kayaking) and the lack of studies investigating this scenario, a great need exists to investigate the functional significance of RM function upon athletic performance in sports of predominantly arm exercise.

# **CHAPTER SIX**

## **PROBLEM STATEMENT**

### **A. SUMMARY OF LITERATURE**

When considering the literature in chapter two to chapter four, several main issues in research on paddlers emerge:

In the sport of kayaking, the paddler's upper body and extremities, together with the paddle become a leverage system to overcome the resistance of the water and move the kayak in a forward direction. Due to the biomechanical nature of the sport of kayaking, the determination of the kinanthropometric profile of paddlers plays an important role in identifying those attributes related to shape, size and proportions of the skeleton that can influence kayak performance.

Numerous studies have been published on the kinanthropometry of paddlers. A consistent finding in the literature is that successful paddlers have greater upper body characteristics (especially upper arm girth) compared to less successful paddlers and non-athletes (Cermak et al., 1975; Tesch & Lindeberg, 1984; Fry & Morton, 1991; Aitken & Jenkins, 1998; Van Someren & Palmer, 2003). In general, these studies revealed that successful paddlers are heavier (Cermak et al., 1975; Tesch & Lindeberg, 1984; Fry & Morton, 1991; Aitken & Jenkins, 1998) and taller (Cermak et al., 1975; Tesch & Lindeberg, 1984; Fry & Morton, 1991) compared to less successful paddlers and non-athletes.

However, only four studies in the literature, found significant correlations between kinanthropometric attributes and kayak performance itself (Fry & Morton, 1991; Van Someren & Palmer, 2003). Only one variable, namely, humerus breadth, predicted kayak 500 m performance (Someren & Palmer, 2003). The other two studies (Bishop, 2000; Olivier & Coetze, 2002) found no significant correlations between their measured kinanthropometric variables and kayak performance. Since the comparative studies do imply that kinanthropometric variables are important, but the studies investigating correlations with performance are inconsistent, more research needs to be done using the second approach.

Previous research on endurance sports, such as cycling and running, showed that the maximum physiological responses to exercise are important determinants for success in these sports. Most studies showed that  $\text{VO}_{2\text{max}}$  significantly correlated with kayak endurance performance (Pickard & Pyke, 1981; Fry & Morton, 1991; Olivier & Coetze, 2002) and that  $\text{VO}_{2\text{max}}$  was the best predictor of kayak endurance performance (Pickard & Pyke, 1981 and Olivier & Coetze, 2002). Another study found that time to exhaustion during the incremental test was also a predictor of kayak endurance performance (Fry & Morton, 1991). However, very little research on the physiological responses to laboratory kayaking, simulating competition (i.e. time trials), exists due to the lack of sophisticated laboratory equipment. The development of the K1 Ergo (Garren, Australia), which provides an accurate simulation of the kayak paddling action, opened up a new research area to investigate physiology during simulated races.

It can be hypothesized that kayaking is a sport which requires exceptional core stability from the paddler, more so compared to other sports performed on land (stable environment), since the paddler needs to perform various actions (circular movements with arms, twisting of the trunk and pushing movements with legs), while keeping his body and the boat stable on an unstable “surface” (water). Therefore, it must be determined if core stability is one of the determining factors that affects kayak performance. To date, this aspect has not been investigated. Even the development of a core stability test battery in order to assess, quantitatively, athletes’ ability to stabilize themselves, has not been done before in any sport.

In the past it was believed that the respiratory system is not a limiting factor to exercise performance in healthy individuals. However, more recently, research has shown evidence of respiratory muscle fatigue after cycling endurance tests (Bye et al., 1984; McConnell et al., 1997; Romer et al., 2002) and after a rowing endurance test (Volianitis et al., 2001). Very little research investigated respiratory muscle fatigue during upper body exercise. Volianitis et al. (2001) suggested that additional demands are placed upon the respiratory muscles during rowing, since entrainment of breathing (locomotion-breathing coupling) takes place and these muscles also have to stabilize the thorax during arm movements. Few studies have investigated the respiratory muscle function of paddlers (Bertholon et al., 1986; Fry & Morton, 1991; Misigoj-Durakovic & Heimer, 1992; Van Someren & Palmer, 2003), and particularly, the incidence of respiratory muscle fatigue after a kayak endurance test has not been studied before.

## **B. PROBLEMS WITH KAYAK RESEARCH IN THE LITERATURE**

A few problems and shortcomings arise within the available literature on the sport of kayaking. The available studies were mainly concerned with the kinanthropometry of sprint paddlers (Cermak et al., 1975; Aitken & Jenkins, 1998; Van Someren & Palmer, 2003), or paddlers equally successful in sprint and endurance events (Fry & Morton, 1991). Only one available study was concerned with the kinanthropometry of endurance paddlers (Olivier & Coetzee, 2002). However, the only kinanthropometric variables which they measured were height, weight and arm span. Thus, there is a lack of data on the kinanthropometric profile of endurance paddlers. The need exists to determine the kinanthropometric attributes of endurance paddlers, since it is clear that the kinanthropometric profile of endurance athletes differs considerably compared to sprint athletes.

A lack of physiological testing on paddlers in the laboratory (especially during endurance performance tests simulating races) can mainly be attributed to the lack of sufficient equipment. The use of non-specific apparatus (arm crank, modified cycling ergometer and isokinetic kayak ergometers) to test paddlers in previous studies, makes it difficult to compare the outcomes of these studies in order to form a better understanding of the specific physiological requirements of the sport of kayaking, particularly the different sub-disciplines (200 m, 500 m, 1000 m, 10 km and 42 km). The only available studies using the K1 Ergo (Garran, Australia) as in this study, investigated the physiological responses to exercise in sprint paddlers (Van Someren & Dunbar, 1997; Van Someren et al., 2000; Bishop, 2000; Bishop et al., 2001; Bishop et al., 2002; Van Someren & Oliver, 2002; Van Someren & Palmer, 2003; Bishop, 2004). Currently, the physiological responses to endurance performance tests in competitive endurance paddlers are still unknown and need to be investigated.

## **C. AIMS OF THE STUDY**

- 1. To scientifically differentiate characteristics of successful paddlers from less successful paddlers.**

*Questions:*

- i) Are there significant differences in the kinanthropometric profile, kayak endurance performance, core stability and respiratory muscle function between Elite and Sub-Elite endurance paddlers?
  - ii) How do the kinanthropometric and physiological attributes of South African paddlers compare to those paddlers from the UK, exposed to more international competition (Van Someren & Palmer, 2003)?
- 2. To determine if respiratory muscle fatigue is present after endurance performance tests in endurance-trained paddlers.**

*Questions:*

- i) Will the 30 min K1 Ergo endurance performance test (EPT) induce respiratory muscle fatigue in competitive endurance paddlers?
- 3. To determine the reliability of laboratory and field tests.**

*Questions:*

What is the test-retest reliability of the:

- i) 30 min K1 Ergo EPT in the laboratory,
- ii) MIP measurements and
- iii) 10 km TT on water?

- 4. To determine the relationships between the different laboratory parameters and kayak endurance performance.**

*Questions:*

- i) Are there significant relationships between the kinanthropometric, respiratory muscle function, maximum aerobic capacity and the 30 min K1 Ergo EPT in the laboratory?
- ii) What are the predictors of kayak endurance performance (30 min K1 Ergo EPT) in the laboratory?
- iii) Are there any significant relationships between the parameters measured in the laboratory and the 10 km TT on the water?

- iv) What are the predictors of kayak endurance performance (10 km water TT) in the field?

## CHAPTER SEVEN

### METHODOLOGY

#### A. STUDY DESIGN

In this descriptive study, four components of kayak performance were studied in a group of male competitive kayak paddlers:

1. The kinanthropometric profile of local competitive kayak paddlers,
2. Kayak endurance performance,
3. Core stability,
4. Respiratory muscle function.

Eight different tests were conducted to assess the four different components.

**Table 1:** The 4 components and tests of the study protocol

Component:	Tests:
1. Kinanthropometric profile	1. Stature, body mass, 7 skinfolds, 5 girths, 3 length measures, 2 breadths.
2. Kayak endurance performance	2. Maximum aerobic capacity 3. 30 min kayak ergometer (K1 Ergo) endurance performance test (EPT) 4. 10 km time trial (TT) on water
3. Core stability	5. Battery of 6 stability tests
4. Respiratory muscle function	6. Flow-volume curve 7. Maximum voluntary ventilation (in 12 s) 8. Maximum inspiratory mouth pressure

#### B. SUBJECTS

Twenty male kayak paddlers volunteered to take part in the study. All subjects completed all tests.

**Characteristics:** The paddlers' mean  $\pm$  SD age, weight and height was  $28 \pm 7$  yr,  $80 \pm 7$  kg and  $184 \pm 7$  cm, respectively. Their competition level ranged from club to national and international level (3 subjects represented South-Africa at the 2003 and 2004 World Marathon Championships, respectively).

**Recruitment:** Four local canoe clubs (Paarl, Milnerton, Peninsula and Maties Canoe clubs), within a 100 km radius from the testing laboratory, were approached for subject recruitment. Information pamphlets, stating the study design and tests involved, were handed out amongst male members of each club. Each kayak paddler who was interested to volunteer for the study placed their name and contact details on a list at their club. After two weeks the lists were collected from the four different clubs. All volunteers were contacted by phone. If the paddler met the inclusion criteria, an appointment was made for the first visit to the testing laboratory.

**Two group selection:** The 20 paddlers were divided into two ability groups. Paddlers who finished the Berg river canoe marathon under the top ten places in either 2002 or 2003, and/or represented the country in international competition in at least one of the three years prior to the study, were selected as the Elite group ( $n = 11$ ). The paddlers who did not qualify under the above criteria, were selected as the Sub-Elite group ( $n = 9$ ).

**Inclusion criteria:** Each paddler had to meet the criteria of at least four years of competitive experience locally and/or internationally, participation in at least two major marathon events per year, for the past four years, and training at least three times per week. They had to be non-smoking, free of any chronic back pain and free of respiratory tract infection for at least four weeks prior to testing.

**Exclusion criteria:** A subject was excluded from the study if he developed respiratory tract infection during the tests, could not perform the tests in the required time period due to any other illness, injury or other responsibilities, or showed an abnormality in resting pulmonary function. All the paddlers presented with normal pulmonary function and were thus included in the study.

**Consent:** All testing procedures and the risks involved with participation, as stated in the consent form (See Appendix A), were explained to each paddler and the opportunity was

given for questions. The paddler agreed to all testing requirements and procedures by giving his written consent. The study protocol was approved by the Research Ethics Committee of Stellenbosch University (Project nr: 2003/024/N).

### C. EXPERIMENTAL OVERVIEW AND PROCEDURES

All but one of the different tests were conducted during four separate visits to the exercise laboratory, Department of Medical Physiology, Stellenbosch University, Tygerberg. All the subjects completed the laboratory tests in the same order. Testing during each visit was arranged as follows:

Visit 1: Explanation of the study protocol and written consent, maximum aerobic capacity test to exhaustion with lactate analysis, familiarization with stability tests, familiarization with respiratory muscle function tests and pulmonary function tests.

Visit 2: Stability tests, anthropometric measurements and respiratory muscle function practice session.

Visit 3: Respiratory muscle function tests (pre-EPT), 30 min K1 Ergo EPT, respiratory muscle function tests (post-EPT).

Visit 4: A repeat of Visit 3 to test the reproducibility of the 30 min K1 Ergo EPT and the respiratory muscle function tests.

Only one test, the 10 km time trial (TT), was conducted on the water at the different canoe clubs. All eight tests were conducted within a maximum period of four weeks. Subjects were asked to maintain their usual diet throughout the duration of the study, not to consume caffeine on the day of testing, to avoid strenuous activity on the day preceding the day of testing and to cease any exercise fifteen hours prior to testing. The four visits of each paddler were scheduled at similar times of the day. A minimum rest period of 24 hours was allowed between visits 1-3. A minimum rest period of 48 hours and a maximum period of 10 days was allowed between the two K1 Ergo endurance performance tests (visit 3 & 4).

## D. MEASUREMENTS AND TESTS

### 1. Anthropometric measurements

All anthropometric measurements were taken with subjects bare footed and dressed in tight fitting clothes.

Stature: Stature was measured with a measuring tape mounted vertically to a wall perpendicular to the floor. The subject stood with his back and heels against the wall. The midline of the body was positioned in-line with the measuring tape behind the subject. A perspex board (32 x 23 cm) was placed firmly on the vertex of the head and, while the head was in the *Frankfort* plane and the subject took a deep breath, the measurement was taken. The measurement was taken to the nearest 0.1 cm.

Sitting height: A chair with an exact height of 45 cm was placed against the wall with the midpoint of the chair width in-line with the mounted measuring tape. The subject was instructed to sit upright with buttocks against the wall, while the feet were placed on the floor and the lower legs were at right angles with the thighs. The subject was also instructed to avoid an arched back. The measurement was taken following the exact procedure as for standing height. The sitting height was then calculated by subtracting the chair height from the measured value to the nearest 0.1 cm.

Arm length: Arm length was taken with a flexible steel tape (*Lufkin*, J. Rabone & sons, England) from the acromiale landmark to the dactylion landmark of the right arm. The subject was instructed to stand upright with his arm straight and relaxed at the side, with the palm placed on the thigh. The upper arm length was taken from the acromiale landmark to the radiale landmark. The lower arm length was taken from the radiale to the styilon landmark. Measurements were taken to the nearest 0.1 cm.

Arm span: A modified method of Hahn (1990) was used to measure arm span. An elastic measuring tape was mounted to the wall more or less at shoulder height of a person with normal height. A black line at the zero cm mark was drawn perpendicular to the floor, about 30 cm up and down from the measuring tape. The subject was instructed to stand with his feet 3-4 cm apart with his right third fingertip just touching the black line. The subject was

instructed to stretch out, with his torso pressed against the wall and his head turned sideways, to obtain the greatest possible span. A pencil mark was made at the third fingertip of the other hand. The span was read to the nearest 0.1 cm.

Body mass: Body mass was measured with an electronic scale (*UWE BW-150* freeweight, 1997 model, Brisbane, Australia) to the nearest 0.1 kg.

Fat percentage: Seven skinfolds were taken at the specific landmark sites as described by Norton et al. (2000) with a skinfold caliper (*Lange*, Cambridge Scientific Industries Inc., Cambridge, Maryland). Each measurement was read 2 seconds after the release of the caliper trigger to the nearest 0.5 mm. The seven skinfold measurements were: triceps, subscapular, biceps, supraspinale, abdominal, front thigh and mid-calf.

Body fat percentage was calculated using the regression equation of Withers et al. (1987) for body density ( $R^2 = 0.75$ , SEE = 0.0058):

$$BD = 1.0988 - 0.0004 \times \sum \text{6 skinfolds (triceps, subscapular, supra-iliac, abdominal, front thigh and medial calf)} \dots \text{eq. 7.1}$$

The regression equation of Siri (1961) was used to calculate percentage body fat:

$$\%BF = 495/BD - 450 \dots \text{eq. 7.2}$$

Girths: Five girths were taken with a flexible steel tape (*Lufkin*, J. Rabone & sons, England) at the specific standardized sites. Measurements were taken to the nearest 0.1cm. The girths were: upper arm (relaxed at the mid-acromiale-radiale point), upper arm (tensed at maximum girth), forearm (maximum girth), chest (at meso-sternal landmark) and calf (maximum girth).

Breadths: The breadths measured included the humerus and femur width. These measurements were taken to the nearest 0.1 cm. The humerus and femur breadths were taken at specific landmarks with an anthropometric caliper (*Fine Line* Engineering, South Africa). These measurements were taken to the nearest 0.2 cm.

Somatotype: Each subject's specific somatotype ratio was calculated from the skinfolds, girth and diameter measurements according to the Heath-Carter method (1967).

Two consecutive scores within 0.2 cm for length measures, 1 mm for skinfold measures and 0.2 kg for weight measures were required. The average of these two measurements was calculated as the final score. All the other measurements were taken once. The ratios for arm length, arm span and sitting height to standing height were calculated.

## 2. Maximum aerobic capacity test

A progressive incremental exercise test to exhaustion, with lactate analysis, was performed on the K1 Ergo to assess maximum aerobic capacity.

Kayak ergometer: All endurance tests in the laboratory were conducted on a calibrated, wind-braked kayak ergometer (K1 Ergo, Garran, Australia). The adjustable footrest was positioned according to the paddler's comfort prior to each test. The K1 Ergo was interfaced with specialized computer software. The software calculated and recorded work and related work indices continuously throughout each test. (See Appendix B)

Gas analysis: Breath-by-breath gas analysis was continuously recorded throughout the incremental test to exhaustion. Expired gases, flow and volumes were sampled through the turbine flow meter and a gas sampling line and analyzed by a cardio-pulmonary metabolic system (*Cosmed Quark b<sup>2</sup>*, Rome, Italy) (See Appendix B). Heart rate (HR) was measured through telemetry (POLAR®, Polar Electro Oy, Finland) and also recorded by the metabolic system. The gas analyzers were calibrated prior to each test with atmospheric gas and known gas concentrations (17.4% O<sub>2</sub>, 3.57% CO<sub>2</sub>, balance N<sub>2</sub>) and the turbine flow meter was calibrated with a 3 L calibration syringe.

Lactate analysis: Whole blood lactate concentrations were measured with an automated blood lactate meter (*Lactate Pro*, Arkray Inc., Kyoto, Japan). Pyne et al. (2000) evaluated the accuracy of the *Lactate Pro* meter in relation to three other lactate analysers and a high level of agreement was found with the *ABL 700* ( $r = 0.98$ ); the *Accusport Lactate Meter* ( $r = 0.97$ ); and the *YSI 2300 Stat* ( $r = 0.99$ ). Blood was sampled via a finger prick with a lancet device (Softclix®, Boehringer Mannheim), before exercise, at termination of the test

and during each workload until a lactate concentration of 4 mmol.L<sup>-1</sup> or higher was registered. With each blood sample, the subject's fingertip was cleaned with an alcohol swab, and after the first drop of blood was wiped off, the next drop of blood was sampled on the lactate strip. Iron drops were applied to the puncture area to stop the bleeding as quickly as possible. A different finger was used with each finger prick.

***Incremental test:*** A progressive incremental protocol to exhaustion was used to determine maximum O<sub>2</sub> consumption (VO<sub>2max</sub>) (or maximum aerobic capacity), maximum heart rate (HR<sub>max</sub>), maximum minute ventilation (VE<sub>max</sub>), maximum breathing frequency (f<sub>bmax</sub>), lactate inflection point (LI), lactate threshold (LT) and ventilatory threshold (VT). The mechanical outcome variables from the incremental test included: peak power output (PPO), and maximum values for stroke lengths (left and right) during the final workload (highest value averaged over 30 s during the last completed workload).

Subjects warmed up for 5 min at 50% of their perceived maximum effort. The exercise test commenced at an initial workload of 75 W and the workload was increased by 25 W every 3 min until the blood lactate concentration reached 4 mmol.L<sup>-1</sup> or more. Each of the 3 min intervals was interrupted with a 30 s rest period for blood sampling. After the subject reached 4 mmol.L<sup>-1</sup>, the workload was increased by 25 W every 2 min until the subject reached exhaustion. On the K1 Ergo, stroke rate is directly proportional to power output. The paddler was therefore instructed to manually maintain the predetermined power output (reflected on the kayak monitor) by increasing his stroke rate during the incremental test. Subjects were considered exhausted if they could not sustain the specific workload for 15 seconds or if they could not reach the new workload within 15 seconds. No subject completed fewer than 6 workloads and no subject completed more than 10 workloads.

The averages of the highest, consecutive 10 s values for VO<sub>2</sub>, HR and VE during the incremental test were calculated as the maximum values.

VT was detected through specialized computer software analysis, using one of the methods introduced by Wasserman et al. (1973). VT was defined as the point where a non-linear increase in minute ventilation (VE) occurred when plotted against VO<sub>2</sub>, expressed as a percentage of VO<sub>2max</sub> (%VO<sub>2max</sub>). The HR and power output (PO) at which VT occurred were also determined through computer software analysis.

LI point was determined by the method used by Bishop (2004). LI point was subjectively detected by hand on a graph ([La] plotted against the corresponding PO), as the PO corresponding to the first increase in blood lactate concentration greater than  $0.4 \text{ mmol.L}^{-1}$  above the resting level. The average of the highest, consecutive 10 sec  $\text{VO}_2$  values at that specific PO was calculated as the LI point, and expressed as a percentage of  $\text{VO}_{2\text{max}}$  (% $\text{VO}_{2\text{max}}$ ). HR at LT was determined as the average HR over the same consecutive 10 sec  $\text{VO}_2$  values at LT.

LT was determined by the method introduced by Heck et al. (1985). LT was subjectively detected, as the PO corresponding to a blood lactate concentration of  $4 \text{ mmol.L}^{-1}$ . The average of the highest, consecutive 10 s  $\text{VO}_2$  values at that specific PO was calculated as the LT, and expressed as a percentage of  $\text{VO}_{2\text{max}}$  (% $\text{VO}_{2\text{max}}$ ). HR at LT was determined as the average HR over the same consecutive 10 s as the  $\text{VO}_2$  values at LT.

### **3. 30 min K1 Ergo EPT**

Subjects completed two 30 min endurance performance tests on the K1 Ergo, on 2 separate occasions, to measure endurance performance. An endurance performance protocol was chosen based on research stating the high validity of this type of endurance performance test (Jeukendrup et al., 1996).

A 30 min test was chosen to ensure a true endurance effort, but also not to demotivate the paddler by making the test too long on the K1 Ergo. A fixed time protocol (30 min) was chosen in order to compare subjects' responses at specific time intervals.

The average power output (PO) achieved during the 30 min EPT served as the measurement of endurance performance. Heart Rate (HR) was recorded at 5 s intervals (POLAR® *Accurex Plus* and *Xtrainer Plus*, Polar Electro Oy, Finland) and downloaded with specialized computer software (POLAR® HR Analysis Software and POLAR® Polar Training Advisor, Polar Electro Oy, Finland). Average PO and stroke lengths (left and right) were calculated continuously for the 30 minutes.

#### **4. 10 km TT on water**

Each subject completed a time trial on the water at their individual canoe clubs under the supervision of the researcher. Each paddler provided his own kayak, paddle and safety gear. The paddlers competed with other paddlers (only some of whom were also participants in the project) to encourage a maximal effort. Four subjects completed the TT at Paarl Canoe Club, five at Milnerton Canoe Club and five at Peninsula Canoe Club. Two of the 10 km routes were circular (2 laps of 5 km each), while the other was an out and back course (four laps of 2.5 km). Water time trial data from only 14 subjects were used for data analysis, since only 14 out of the 20 subjects completed at least two water time trials. HR was recorded using the same method as during the 30 min EPT on the K1 Ergo. Time to complete the time trial route was recorded to the nearest second. The better time of the two time trials were used for data analysis.

#### **5. Stability test battery**

A practical, non-invasive, self-developed test battery was compiled to assess the paddler's 'ability to stabilize' himself. Co-activation of the antagonistic flexor-extensor muscles of the trunk is necessary to provide mechanical stability to the lumbar spine (Cholewicki et al., 1997) and core stability is a complex interplay of the major joints and muscles of the pelvis, spine and limbs (Wisbey-Roth, 2001). In order to measure this complex interaction of the group of muscles responsible for core stability, six tests were developed to incorporate a variety of body positions and movements in which stability could be tested. In four of the six tests a stability ball (GymnastikBall®, Ledragomma, Italy) was used, while the two remaining tests involved the use of an aneroid sphygmomanometer and the body alone, respectively. All six tests were performed on gymnastic mats. Subjects were instructed to wear tight, sleeveless shirts and tight fitted shorts to assist the researcher to observe body alignment during the stability tests. Each subject had one practice session for each of the six tests prior to the day of testing. Due to the very high requirements for balance in tests three, four and six, subjects were given a second chance to perform these three tests, and the best score was taken as the final score. Subjects did not warm up for the six tests. Photo illustrations of the six stability tests are given in Appendix C.

Test 1: The subject had to lie on his side with his legs straight, his feet and legs together in the frontal plane, and then push his body upwards from his one elbow nearest to the floor until his shoulder, hip and knee joints nearest to the floor, were in line with one another (bridge position). The subject was instructed to keep this position for as long as possible. Time (in seconds) was measured from positioning until the subjects' hips started to sag (the bridge position was disturbed). The test was performed on the left and right sides.

Test 2: An aneroid sphygmomanometer (CE 0483) in a modified cuff was used in this test. The cuff was strapped around the subject's waist so that the 'bladder' was positioned on the most curved part of the lumbar spine. The subject had to lie on his back, with his hips and knees at 90° angles and his lower legs parallel to the floor. His arms and hands were placed behind his head, and his head was tilted forward and upwards (starting position). The pressure cuff was inflated up to 100 mmHg. The subject had to lower his legs, by extending his hips and keeping his knees at a 90° angle, until his heels touched the floor, and then return to the starting position. Throughout the movement the subject had to push his lower back into the floor. The number of repetitions in one minute was counted. A repetition was not counted if the pressure in the cuff dropped below 60 mmHg. The subject was allowed to look at the pressure gauge during the test.

Test 3: The subject had to position himself, in the prone position, with his upper legs on the top, middle part of the stability ball with his hands on the floor and his arms straight, perpendicular to the floor. A line was drawn with masking tape on the floor at the tips of the subject's middle fingers (starting position). The subject rolled forward on the ball, whilst "stepping" forward with the hands, until his shins were on the top, middle part of the ball. A line with masking tape was drawn on the floor, at the back of the subject's hands (end position). The subject was instructed to move back and forth between the starting and end positions as quickly as possible, without losing his balance on the ball. The number of repetitions in one minute was counted. A repetition was not counted if the subject's hands were not behind the tape at the starting position and/or not over the tape at the end position. The test was terminated if the subject fell off the ball.

Test 4: The subject had to position himself with his shoulder blades on the top, middle part of the ball, his arms folded across his chest, and his feet on the floor with his knees bent at 90° and his hip joint in line with his knee joint. The subject was instructed to extend the

knee of one leg, while supporting with the other leg. Time (in seconds) was measured as soon as the leg was extended until the subject lowered his leg, sagged his hips, and/or moved his supporting foot. The test was performed with the left and right legs.

Test 5: The subject had to position himself with his shins on the top, middle part of the ball and his hands on the floor with his arms straight, perpendicular to the floor. His legs had to be straight and his shoulder, hip and knee joints had to be in line with one another. The subject was instructed to lift one leg off the ball and to keep that position for as long as possible (the lifted leg was not allowed to touch the ball). Time (in seconds) was measured as soon as one leg was lifted off the ball until the subject either fell off the ball or disturbed the ‘in line’ position of the shoulder, hip and knee joint of the leg on the ball. The test was performed with the left and right legs.

Test 6: The subject had to position himself, supine, with his feet and calves on the top, middle part of the ball, his shoulders and head on the floor, and with his arms folded across his chest. His hips had to be lifted upwards until the shoulder, hip and knee joints were in line with one another in a bridge position. The subject was instructed to lift one leg off the ball and keep the position for as long as possible. Time (in seconds) was measured as soon as the leg was lifted off the ball until the subject’s leg fell off the ball or the bridge position was disturbed. The test was performed with the left and right legs.

All six tests were measured once, followed by repeats of those tests where subjects had a second chance. There was a rest period of 2 min between each test. The score(s) for each test, whether it was time in seconds or number of repetitions in one minute, were added together. Each subject received a single score which reflected his performance within the group. The subject with the highest score reflected the best performance. This single score unit of measurement for the six stability tests was named the *Stability-6 Score Index*.

## **6. Pulmonary function**

Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second (FEV<sub>1</sub>) and Peak Expiratory Flow Rate (PEF or PEFR) were measured by means of a Flow-volume curve. This test was conducted to measure functional lung capacity as well as to assess normal pulmonary function. The spirometric variables were measured with a unit using a turbine

flow meter for volume measurements and the *Spirometry reader 2000* (*Cosmed Quark b<sup>2</sup>*, Rome, Italy). Calculations were made with *Spirometry* PC software according to the spirometry standards of the American Thoracic Society (ATS) and the European Respiratory Society (ERS). Each subject performed the maneuvers while seated and wearing a nose clip. The subject had to seal his mouth around a carton mouthpiece connected to the flow meter, take three normal breaths, then inhale to total lung capacity (TLC) and immediately exhale maximally, as rapidly and as forcefully as possible. Each subject performed a minimum of three and a maximum of eight maneuvers. At least two flow-volume curves, of which the FVC and FEV<sub>1</sub> did not differ by more than 5%, were required from each subject. The curve with the greatest sum of FVC and FEV<sub>1</sub> was selected as the final measurement.

Maximum Voluntary Ventilation (MVV) in 12 seconds was measured to assess basic respiratory muscle endurance. The subject was instructed to inhale and exhale through the mouthpiece as maximally and as rapidly as possible for 12 s. MVV was performed at least 3 times and the best measurement of two measurements within 5% variance was taken. Ventilated air was measured in liters per minute (L/min).

## 7. Respiratory muscle strength

Maximum Inspiratory Mouth Pressure (MIP) was measured with an in-house device to assess respiratory muscle strength. A modification of the method of Black & Hyatt (1969) was used. The device consisted of a two-way valve (Hans-Rudolph, Kansas City, USA). The one opening was connected to a plastic cylinder, 120 mm in length and 38 mm in diameter, with a small leak (1.5 mm in diameter) at the distal end of the cylinder, to prevent the subject from sucking with the muscles of the face and pharynx with a closed glottis. The other opening was open to the atmosphere through which expiration took place. A replaceable rubber mouthpiece was connected to the valve. The device was connected through a side port to a digital pressure meter (*Crystal*, Model 33, Crystal Engineering Corporation, California, USA), connected to specialized PC software.

The subject, seated and wearing a nose clip, had to exhale to residual volume (RV) and inhale through the device as forcefully and rapidly as possible. Pressure (in mmH<sub>2</sub>O) was measured at a sampling frequency of 2 Hz, and displayed on the computer monitor which was also visible to the subject. Five technically satisfactory maneuvers were performed and

the average value of the highest 3 measurements, within 5% variability, was considered as MIP. MIP was measured 15 min before and 2 min after the 30 min K1 Ergo EPT to estimate respiratory muscle fatigue. The best MIP measurement out of four MIP measurements (pre and post EPT measurements during visit 3 and visit 4) was used as the value (cmH<sub>2</sub>O) for respiratory muscle strength. The pre and post EPT MIP measurements of the best 30 min K1 Ergo EPT were used to determine respiratory muscle fatigue.

#### E. STATISTICAL ANALYSIS

Descriptive statistics were presented as mean  $\pm$  SD, unless otherwise indicated. Coefficients of variation (CV) were calculated to illustrate large inter-individual variation in some of the outcome variables ( $[SD/\text{mean}] \times 100$ ). Unpaired Student's t-tests were used to determine significant differences in the measured variables between the Elite and Sub-Elite paddlers. The outcome variables from this study were compared to the data of Van Someren & Palmer (2003) using Independent Student's t-test for mean values. Pearson product moment correlations were calculated to determine significant relationships between maximum aerobic capacity, pulmonary function, kinanthropometry, core stability, and the outcome variables of the two performance tests, i.e. average PO during the 30 min K1 Ergo EPT and the total time (s) for the 10 km water TT.

The reliability of the MIP measurements, 30 min K1 Ergo EPT and the 10 km water TT was determined using intraclass correlation coefficients. Stepwise multiple regression analyses were performed to determine the predictors of the two performance tests (30 min K1 Ergo EPT and the 10 km water TT). Regression equations were generated to obtain the lowest possible standard error of prediction. Multiple regression analysis results were reported as R<sup>2</sup> (multiple correlation coefficient), R<sup>2</sup><sub>adjusted</sub> (adjusted coefficient of determination) and ΔR<sup>2</sup> (change in the coefficient of determination). The error of prediction was calculated as the standard error of the estimate. The level of significance was set at  $P < 0.05$ .



## **CHAPTER EIGHT**

### **RESULTS**

#### **A. DESCRIPTIVE STUDY AND COMPARISONS BETWEEN COMPETITIVE PADDLERS**

##### **1. Introduction**

One of the aims of the study was to determine if there are differences in the kinanthropometric and physiological attributes between successful and less successful paddlers. Therefore the total group of paddlers ( $n = 20$ ) of the present study was divided into Elite ( $n = 11$ ) and Sub-Elite paddlers ( $n = 9$ ). Another aim was to determine to what extent the paddlers of the present study compare physically and physiologically to international level paddlers. For this purpose, the kinanthropometric and physiological attributes of the total group and the Elite paddlers were compared to the international level (Int) and national level (Nat) paddlers of Van Someren & Palmer (2003), respectively. This study of Van Someren & Palmer (2003) was chosen as reference data, since they measured similar parameters to those in the present study, and it was also the most recent data available in the literature.

##### **2. Kinanthropometry**

###### **2.1 Kinanthropometric differences between Elite and Sub-Elite paddlers.**

There were no significant differences between the two groups for most of the kinanthropometric variables, except sitting height as a percentage of stature (Table 2). The Elite paddlers had a significantly greater sitting height (2% greater) than the Sub-Elite paddlers ( $P = 0.03$ ).

**Table 2:** Kinanthropometric characteristics (mean  $\pm$  SD) (Range) of the Elite and Sub-Elite paddlers.

Variable:	Elite Paddlers (n = 11)		Sub-Elite Paddlers (n = 9)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Age (yrs)	26 $\pm$ 6	18 – 34	31 $\pm$ 7	22 – 41
Weight (kg)	78.6 $\pm$ 6.9	70.8 – 91.2	81.9 $\pm$ 6.9	69.9 – 91.6
Stature (cm)	182.7 $\pm$ 7.2	173.6 – 197.7	186.3 $\pm$ 6.3	178.7 – 194.3
Sitting Height (cm)	97.9 $\pm$ 3.1	93.4 – 103.6	97.8 $\pm$ 4.5	90.5 – 105.1
Sitting Height as % of Stature	53.6 $\pm$ 0.9 *	52.4 – 55.3	52.5 $\pm$ 1.2	50.6 – 54.6
Arm length (cm)	81.9 $\pm$ 3.8	76.0 – 87.5	83.7 $\pm$ 2.8	80.5 – 89.5
Arm span (cm)	190.5 $\pm$ 9.0	178.0 – 204.9	195.8 $\pm$ 8.6	180.8 – 207.3
Sum of 4 skinfolds (mm)	29.8 $\pm$ 8.8	19.5 – 49.0	31.3 $\pm$ 4.5	25.5 – 40.0
Body fat (%)	11.6 $\pm$ 3.5	5.8 – 17.8	11.1 $\pm$ 1.5	8.9 – 13.4
<b>Girths (cm)</b>				
Upper arm (relaxed)	32.6 $\pm$ 2.0	29.7 – 35.6	32.8 $\pm$ 1.6	30.4 – 34.7
Upper arm (tensed)	34.5 $\pm$ 1.8	31.6 – 37.1	34.4 $\pm$ 1.4	32.3 – 36.5
Forearm	28.6 $\pm$ 1.0	26.9 – 30.1	29.0 $\pm$ 1.0	27.8 – 30.4
Chest	104.5 $\pm$ 6.0	98.1 – 118.2	107.6 $\pm$ 6.2	99.4 – 115.6
Calf	36.2 $\pm$ 2.0	33.9 – 39.4	35.0 $\pm$ 5.2	21.7 – 38.3
Humerus breadth (cm)	7.2 $\pm$ 0.5	6.8 – 8.2	7.0 $\pm$ 0.5	6.2 – 7.6
Femur breadth (cm)	9.9 $\pm$ 0.3	9.2 – 10.6	10.0 $\pm$ 0.7	8.6 – 10.8

4 skinfolds:  $\Sigma$  (biceps + triceps + subscapular + suprailiac)

body fat % was calculated from the sum of 6 skinfolds using the equation of Withers et al. (1987)

\* Significantly greater than the Sub-Elite paddlers,  $P < 0.05$ .

## 2.2 Comparisons of kinanthropometric variables of the present study with the findings of Van Someren & Palmer (2003).

In Table 3 the kinanthropometry of the total group ( $n = 20$ ) of the present study is compared to the International (Int) ( $n = 13$ ) and National level (Nat) ( $n = 13$ ) paddlers of Van Someren & Palmer (2003). Compared to the Int paddlers, the total group had significantly lower body fat percentages, upper arm girths (tensed), forearm girths, calf girths and humerus breadths (all  $P < 0.05$ ). There were great similarities between the total group and the Nat paddlers. The only exceptions were mean sitting height and chest girth. The Elite paddlers of the present study were similar in weight to the Nat paddlers, but significantly lighter than the Int paddlers. The Elite paddlers also had significantly smaller body fat percentages, humerus breadths, upper arm girths (tensed), forearm girths and calf girths compared to the Int paddlers (all  $P < 0.05$ ). Sitting heights and upper arm girths (relaxed) of the Elite paddlers were significantly greater compared to the Nat paddlers (both  $P < 0.05$ ).

**Table 3:** Kinanthropometric characteristics (mean  $\pm$  SD) of the total group compared to the International level (Int) and National level (Nat) paddlers of Van Someren & Palmer (2003).

Variable:	Total Group (n = 20)	Van Someren & Palmer (2003) Int (n = 13)	Nat (n = 13)
Age	28 $\pm$ 7	26 $\pm$ 5	25 $\pm$ 6
Weight	80.1 $\pm$ 7.0	84.5 $\pm$ 4.9	79.9 $\pm$ 7.8
Stature	184.3 $\pm$ 6.9	182.9 $\pm$ 5.6	182.4 $\pm$ 5.5
Sitting Height (cm)	97.9 $\pm$ 3.7 *	95.8 $\pm$ 2.9	94.4 $\pm$ 2.6
Sitting Height as % of stature	53.1 $\pm$ 1.1	52.4	51.8
Arm span (cm)	192.9 $\pm$ 9.0	191.0 $\pm$ 8.3	191.4 $\pm$ 7.1
Sum of 4 skinfolds (mm)	30.5 $\pm$ 7.1	31.6 $\pm$ 9.5	30.8 $\pm$ 11.9
Body fat (%)	11.3 $\pm$ 2.7 #	14.1 $\pm$ 2.9	12.9 $\pm$ 3.6
<u>Girths (cm)</u>			
Upper arm (relaxed)	32.8 $\pm$ 1.7	32.3 $\pm$ 1.7	30.4 $\pm$ 1.9
Upper arm (tensed)	34.3 $\pm$ 1.8 #	36.9 $\pm$ 1.3	35.2 $\pm$ 2.1
Forearm	28.8 $\pm$ 1.0 #	30.3 $\pm$ 1.1	28.9 $\pm$ 1.2
Chest	105.9 $\pm$ 6.1 *	106.9 $\pm$ 2.4	101.7 $\pm$ 5.1
Calf	35.7 $\pm$ 3.7 #	38.9 $\pm$ 1.5	37.3 $\pm$ 2.7
<u>Breadths (cm)</u>			
Humerus	7.1 $\pm$ 0.5 #	7.6 $\pm$ 0.2	7.2 $\pm$ 0.3
Femur	9.9 $\pm$ 0.5	10.0 $\pm$ 0.4	9.8 $\pm$ 0.3

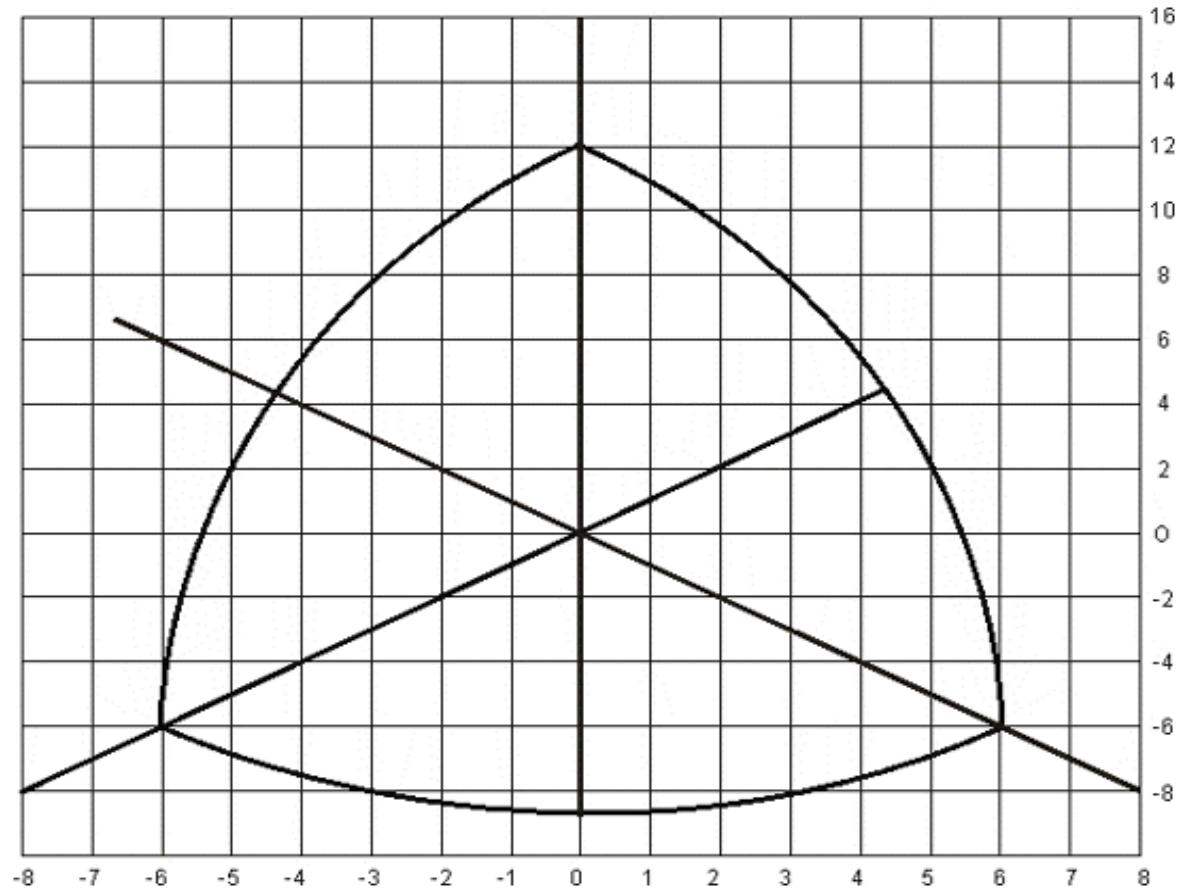
4 skinfolds:  $\Sigma$  (biceps + triceps + subscapular + suprailiac)

\* significantly different from Nat paddlers ( $P < 0.05$ )

# significantly different from Int paddlers ( $P < 0.05$ )

## 2.3 Somatotype

There were no significant differences in somatotype scores between the Elite and Sub-Elite paddlers. One subject was an outlier (-0.34, -4.6) on the somatochart (Fig. 1), but it did not influence the outcome of the mean somatotype classification. Overall, the paddlers in this study can be described as balanced mesomorph. This indicates that the paddlers have body shape characteristics of large muscle mass with broad bone diameters of their skeletons, relative to their stature. When the somatotype scores of the total group and the Elite paddlers were compared to the Int and Nat paddlers of Van Someren & Palmer (2003), respectively, only ectomorphy was significantly greater in the total group compared to the Int paddlers ( $P < 0.05$ ).



**Table 4:** Somatotype characteristics (mean  $\pm$  SD) (Range) of the Elite and Sub-Elite paddlers.

Variable:	Elite Paddlers (n = 11)	Sub-Elite Paddlers (n = 9)	
Endomorphy	2.4 $\pm$ 0.8	1.4 – 3.9	2.4 $\pm$ 0.6
Mesomorphy	4.7 $\pm$ 1.0	3.4 – 6.3	3.9 $\pm$ 1.4
Ectomorphy	2.6 $\pm$ 0.7	1.5 – 3.6	2.9 $\pm$ 0.7

**Table 5:** Somatotype characteristics (mean  $\pm$  SD) of the total group compared to the International level (Int) and National level (Nat) paddlers of Van Someren & Palmer (2003).

Variable:	Total Group (n = 20)	Van Someren & Palmer (2003)	
		Int (n = 13)	Nat (n = 13)
Endomorphy	2.4 $\pm$ 0.7	2.6 $\pm$ 0.8	2.6 $\pm$ 1.1
Mesomorphy	4.4 $\pm$ 1.2	4.9 $\pm$ 0.9	4.0 $\pm$ 1.3
Ectomorphy	2.7 $\pm$ 0.7 #	2.1 $\pm$ 0.7	2.7 $\pm$ 1.4

# significantly different from the Int paddlers ( $P < 0.05$ )

### 3. Kayak endurance performance

#### 3.1 Cardiorespiratory differences between Elite and Sub-Elite paddlers

The maximum aerobic capacities of the Elite and Sub-Elite paddlers are presented in Table 6. A maximum aerobic capacity test can be considered a true maximum test if one or more of the following occurred:

- i) oxygen consumption ( $VO_2$ ) showed a plateau towards the end of the incremental test.
- ii) the respiratory exchange ratio (RER) reached a value of 1.15 or higher.
- iii)  $HR_{max}$  during the test reached more than 90% of the age predicted  $HR_{max}$ .

During the incremental test on the K1 Ergo, the Elite paddlers and the Sub-Elite paddlers reached a RER of  $1.16 \pm 0.09$  and  $1.23 \pm 0.14$ , respectively. The Elite paddlers reached  $93 \pm 2.3\%$  of age predicted  $HR_{max}$  ( $193 \pm 3$  bpm) and the Sub-Elite paddlers reached  $95 \pm 4.8\%$  of age predicted  $HR_{max}$  ( $190 \pm 5.0$  bpm). All the subjects showed a plateau in  $VO_2$  towards termination of the incremental test. Therefore, the maximum aerobic capacity tests can be considered as true maximal efforts.

The Elite paddlers showed statistically significantly greater values for relative  $VO_{2max}$  ( $P = 0.046$ ), PPO ( $P = 0.04$ ) and PPO to weight ratio ( $P = 0.006$ ) compared to the Sub-Elite

paddlers. There were no significant differences in absolute  $\text{VO}_{2\text{max}}$ ,  $\text{HR}_{\text{max}}$ ,  $\text{VE}_{\text{max}}$  and any of the threshold variables between Elite and Sub-Elite paddlers.

**Table 6:** Cardiorespiratory characteristics (mean  $\pm$  SD) (Range) of the Elite and Sub-Elite paddlers.

Variable:	Elite Paddlers (n = 11)		Sub-Elite Paddlers (n = 9)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
$\text{VO}_{2\text{max}} (\text{L} \cdot \text{min}^{-1})$	$4.4 \pm 0.3$	$3.9 - 5.0$	$4.1 \pm 0.5$	$3.1 - 4.7$
$\text{VO}_{2\text{max}} (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$	$55.6 \pm 7.0 *$	$45.6 - 65.7$	$49.6 \pm 5.6$	$42.1 - 59.7$
$\text{HR}_{\text{max}} (\text{bpm})$	$180 \pm 8$	$180 - 194$	$181 \pm 10$	$169 - 198$
$\text{VE}_{\text{max}} (\text{L} \cdot \text{min}^{-1})$	$156 \pm 20$	$156 - 203$	$151 \pm 20$	$116 - 174$
PPO (W)	$286 \pm 23 *$	$247 - 310$	$261 \pm 27$	$219 - 301$
PPO:Weight ( $\text{W} \cdot \text{kg}^{-1}$ )	$3.7 \pm 0.4 *$	$3.2 - 4.3$	$3.2 \pm 0.2$	$2.9 - 3.4$
<u>Thresholds:</u>				
Lactate Inflection Point (LI) as % $\text{VO}_{2\text{max}}$	$68.3 \pm 9.1$	$53.9 - 79.5$	$62.4 \pm 10.5$	$48.6 - 77.2$
Ventilatory Threshold (VT) as % $\text{VO}_{2\text{max}}$	$72.3 \pm 4.7$	$64.0 - 79.0$	$72.8 \pm 6.2$	$61.0 - 82.0$
Lactate Threshold (LT) as % $\text{VO}_{2\text{max}}$	$82.9 \pm 6.8$	$69.8 - 93.0$	$79.8 \pm 7.8$	$66.0 - 90.8$

\* Significantly greater than the Sub-Elite paddlers,  $P < 0.05$ .

### 3.2 Comparisons of cardiorespiratory variables of the present study with the findings of Van Someren & Palmer (2003).

In Table 7 the maximum aerobic capacity of the total group of the present study was compared to the Int and Nat paddlers of Van Someren & Palmer (2003). Compared to the Int and Nat paddlers, the total group reached significantly lower  $\text{HR}_{\text{max}}$  values (but higher PPO values) during the incremental test. The same results were obtained for the comparisons between the Elite paddlers in our study and the Int and Nat paddlers in their study.

**Table 7:** Cardiorespiratory characteristics (mean  $\pm$  SD) of the total group compared to the International level (Int) and National level (Nat) paddlers of Van Someren & Palmer (2003).

Variable:	Total Group (n = 20)	Van Someren & Palmer (2003)		
		Int (n = 13)	Nat (n = 13)	
$\text{VO}_{2\text{max}} (\text{L} \cdot \text{min}^{-1})$	$4.2 \pm 0.4$	$4.5 \pm 0.6$	$4.3 \pm 0.4$	
$\text{VO}_{2\text{max}} (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$	$52.9 \pm 7.0$	$52.6 \pm 4.9$	$54.5 \pm 5.6$	
$\text{HR}_{\text{max}} (\text{bpm})$	$180 \pm 8 * \#$	$190 \pm 12$	$187 \pm 7$	
PPO (W)	$275 \pm 27.2 * \#$	$250.5 \pm 31.5$	$229.1 \pm 19.9$	
<u>Thresholds:</u>				
Lactate Threshold (LT) as % $\text{VO}_{2\text{max}}$	$81 \pm 7.3$	$80.5 \pm 5.6$	$82.9 \pm 3.9$	

\* significantly different from Nat paddlers ( $P < 0.05$ )

# significantly different from Int paddlers ( $P < 0.05$ )

### 3.3 Differences in the outcome variables of the 30 min K1 Ergo endurance performance test (EPT) between Elite and Sub-Elite paddlers.

The Elite paddlers maintained a significantly higher average PO (15% higher,  $P = 0.02$ ), covered a longer distance (366 m further,  $P = 0.02$ ) and achieved a greater average back stroke length (6% greater,  $P = 0.02$ ) during the 30 min K1 Ergo EPT, compared to the Sub-Elite paddlers (Table 8). There were no significant differences in the average HR achieved between the two groups during the endurance performance test.

**Table 8:** Outcome variables of the 30 min K1 Ergo EPT (mean  $\pm$  SD) (Range) of the Elite and Sub-Elite Paddlers.

Variable:	Elite Paddlers (n = 11)		Sub-Elite Paddlers (n = 9)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Average PO (W)	233 $\pm$ 22 *	197 – 266	203 $\pm$ 28	165 – 260
Distance (m)	7059 $\pm$ 240 *	6628 - 7447	6693 $\pm$ 338	6221 – 7361
Average HR (bpm)	168 $\pm$ 10	164 – 189	164 $\pm$ 14	145 – 182
Average Back Stroke Length (m)	1.59 $\pm$ 0.06 *	1.49 – 1.67	1.50 $\pm$ 0.09	1.34 – 1.62

\* Significantly greater than the Sub-Elite paddlers,  $P < 0.05$ .

In total, the group covered a distance between 6.2 and 7.5 km during the 30 min K1 Ergo EPT ( $6895 \pm 336.5$  m). Their average PO ( $220 \pm 28.8$  W) and HR ( $166 \pm 12.0$  bpm) were equal to 80% and 92% (respectively) of the PPO and  $HR_{max}$  achieved during the maximum aerobic capacity test which was also performed on the K1 Ergo. However, there was quite a range between the minimum and maximum values within the total group for distance (6221 – 7447 m), average PO (165 – 266 W) and average HR (145 – 189 bpm).

### 3.4 Differences in the outcome variables of the 10 km water time trial (TT) between Elite and Sub-Elite paddlers.

The 10 km water time trials were completed by 7 Elite and 7 Sub-Elite paddlers (Table 9). The Elite paddlers covered the 10 km time trial on the water in a significantly shorter time (3 min 24 s) compared to the Sub-Elite paddlers ( $P = 0.02$ ). There were no significant differences in average HR during the 10 km water time trial between the two groups.

**Table 9:** Outcome variables during the 10 km water time trial (mean  $\pm$  SD) of the Elite and the Sub-Elite paddlers.

Variable:	Elite paddlers (n = 7)		Sub-Elite paddlers (n = 7)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Time (min:s)	44:10 $\pm$ 01:17 *	42:11 – 46:07	47:34 $\pm$ 03:14	43:54 – 52:21
Average HR (bpm)	166 $\pm$ 9	154 – 178	169 $\pm$ 12	150 – 181

\* Significantly faster than the Sub-Elite paddlers,  $P < 0.05$ .

The total group (n = 14) had a 10 km TT time of  $45:52 \pm 02:57$  (min:s). The average HR during the TT of  $167 \pm 10$  bpm was 92% of the maximum HR achieved during the maximum aerobic capacity test. The average HR was similar to that achieved during the 30 min K1 Ergo EPT.

#### 4. Core stability

Table 10 depicts the results of the stability test battery of the Elite and the Sub-Elite paddlers. No significant differences were found in any of the six individual core stability tests, or the core stability index between the Elite and Sub-Elite paddlers. All the individual core stability test results were characterized by large inter-individual variations, implying that there were large differences between subjects. The coefficients of variation (CV) for the Elite paddlers ranged from 23 to 135% and for the Sub-Elite paddlers from 13 to 99%.

**Table 10:** Individual core stability test variables (mean  $\pm$  SD) (Range) and the core stability index of the Elite and Sub-Elite paddlers.

Variable:	Elite paddlers (n = 11)			Sub-Elite paddlers (n = 9)		
	Mean $\pm$ SD	Range	CV (%)	Mean $\pm$ SD	Range	CV (%)
<b>Individual tests:</b>						
Test 1 (s)	140.1 $\pm$ 42.8	76.9 – 230.5	31	127.4 $\pm$ 31.4	75.5 – 164.8	25
Test 2 (reps/min)	39 $\pm$ 9	27 – 63	23	31 $\pm$ 13	8 – 43	42
Test 3 (reps/min)	17 $\pm$ 5	11 – 29	29	15 $\pm$ 4	7 – 21	27
Test 4 (s)	20.4 $\pm$ 27.5	2.8 – 98.7	135	17.4 $\pm$ 17.3	2.5 – 49.1	99
Test 5 (s)	66.0 $\pm$ 17.5	33.6 – 98.5	27	66.2 $\pm$ 8.8	56.3 – 79.5	13
Test 6 (s)	70.8 $\pm$ 33.3	3.5 – 111.6	47	15.8 $\pm$ 12.5	4.3 – 38.5	79
<b>Core Stability Index</b>	<b>591 <math>\pm</math> 151</b>	<b>332 – 837</b>	<b>26</b>	<b>500 <math>\pm</math> 98</b>	<b>333 – 638</b>	<b>19.6</b>

Refer to pages 68 and 69 in the Methodology for the description of the individual tests 1 – 6.

## 5. Respiratory muscle function

### 5.1 Differences in respiratory muscle function between the Elite and Sub-Elite paddlers.

There were no significant differences in FVC, FEV<sub>1</sub> and PEF between the two groups (Table 11). The Elite paddlers had a significantly greater MVV (12% greater,  $P = 0.02$ ) compared to the Sub-Elite paddlers. The mean respiratory muscle strength (measured as MIP) of the Elite paddlers were 6.1 cmH<sub>2</sub>O higher compared to the Sub-Elite paddlers ( $P = 0.02$ ).

**Table 11:** Respiratory muscle function variables (mean  $\pm$  SD) (Range) of the Elite and the Sub-Elite paddlers.

Variable:	Elite paddlers (n = 11)		Sub-Elite paddlers (n = 9)	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
<u>Pulmonary Function:</u>				
FVC (L)	6.8 $\pm$ 0.9	5.2 – 8.4	6.8 $\pm$ 1.0	4.9 – 8.0
FEV <sub>1</sub> (L)	5.4 $\pm$ 0.5	4.5 – 6.1	5.4 $\pm$ 0.8	3.9 – 6.4
PEF (L.s <sup>-1</sup> )	11.8 $\pm$ 1.7	9.6 – 14.0	11.3 $\pm$ 2.2	7.7 – 14.2
MVV (L.min <sup>-1</sup> )	220.3 $\pm$ 16.7 *	192.9 – 255.6	182.2 $\pm$ 39.7	120.5 – 228.4
<u>Respiratory Muscle Strength:</u>				
MIP (cmH <sub>2</sub> O)	120.3 $\pm$ 4.5 *	115.0 – 128.1	114.2 $\pm$ 5.4	105.8 – 122.7

\* Significantly greater than the Sub-Elite paddlers,  $P < 0.05$ .

### 5.2 Comparison of respiratory muscle function of the present study with the findings of Van Someren & Palmer (2003).

In Table 12, the respiratory muscle function results of the total group of the present study are compared to the Int and Nat paddlers of Van Someren & Palmer (2003). There were no significant differences in the respiratory muscle function variables between the total group and the Int paddlers. The total group did, however, have a significantly higher FVC and FEV<sub>1</sub> compared to the Nat paddlers (both  $P < 0.05$ ). Similarly, there were no differences in respiratory muscle function between the Elite and Int paddlers, however, the Elite paddlers had significantly higher FVC's and FEV<sub>1</sub>'s compared to the Nat paddlers (both  $P < 0.05$ ).

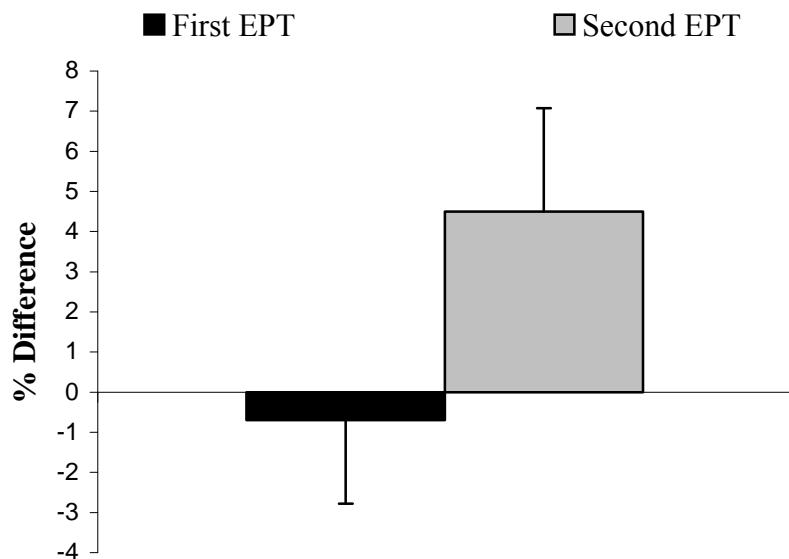
**Table 12:** Respiratory muscle function (mean  $\pm$  SD) of the total group compared to the International level (Int) and National level (Nat) paddlers of Van Someren & Palmer (2003).

Variable:	Total Group (n = 20)	Van Someren & Palmer (2003)	
		Int (n = 13)	Nat (n = 13)
<u>Pulmonary Function:</u>			
FVC (L)	6.8 $\pm$ 0.9 *	6.3 $\pm$ 0.7	6.0 $\pm$ 0.6
FEV <sub>1</sub> (L)	5.4 $\pm$ 0.6 *	5.3 $\pm$ 0.6	4.9 $\pm$ 0.6
PEF (L.s <sup>-1</sup> )	11.6 $\pm$ 1.9	12.7 $\pm$ 1.6	11.5 $\pm$ 1.4

\* significantly different from Nat paddlers ( $P < 0.05$ )

## B. RESPIRATORY MUSCLE FATIGUE

Respiratory muscle fatigue was defined as a significant decrease in maximum inspiratory mouth pressure (MIP) after the 30 min K1 Ergo EPT. There were no significant differences between pre and post MIP measurements during either of the two performance tests ( $P > 0.05$ ) (Fig. 2). There was no difference (mean  $\pm$  SEM) between pre and post MIP measurements during the first EPT. There was a non significant tendency towards a difference of  $4.5 \pm 2.6\%$  between pre and post MIP measurements during the second EPT ( $P = 0.34$ ).



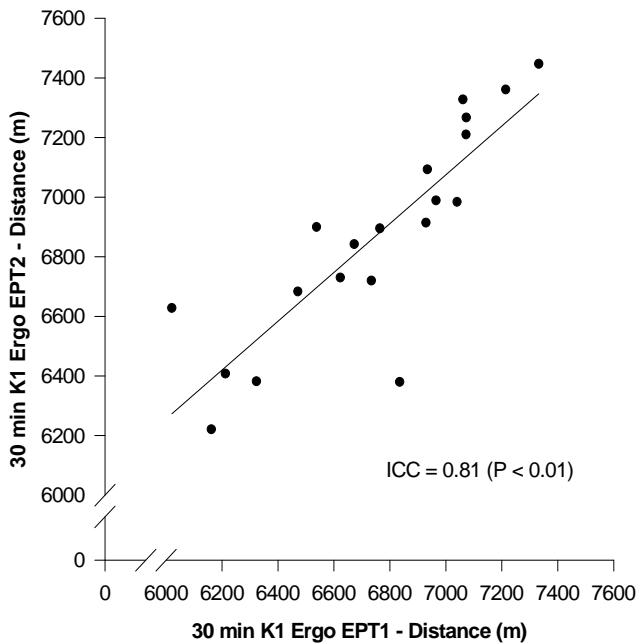
**Figure 2:** Percentage differences (mean  $\pm$  SEM) between pre- and post-test measurements of MIP during the first and second 30 min K1 Ergo EPTs

## C. THE RELIABILITY OF LABORATORY AND FIELD TESTS

Intraclass correlation coefficients between the outcome variables of the first and second laboratory tests (30 min K1 Ergo EPT and MIP) and the field test (10 km Water TT), conducted on two separate occasions, revealed the repeatability of these tests (Table 13 and Fig. 3). Highly significant intraclass correlations coefficients were found between the first and second 30 min K1 Ergo EPT for distance ( $r = 0.81, P < 0.01$ ) (Fig. 3) and average PO ( $r = 0.88, P < 0.01$ ). A moderate, but significant intraclass correlation coefficient of  $r = 0.76$  ( $P < 0.01$ ) was found between the first and second baseline MIP measurements. A highly significant intraclass correlation coefficient of  $r = 0.95$  ( $P < 0.01$ ) was found between the two 10 km time trials on the water.

**Table 13:** Comparisons between the first and second measurements (mean  $\pm$  SD) (Range) of the outcome variables of the 30 min K1 Ergo EPT, MIP measurements and the 10 km water TT.

Variable:	n	Test 1	Test 2	ICC	P Value
<u>30 min K1 Ergo EPT</u>					
Average PO (W)	20	$209 \pm 27.6$ (164 – 262)	$218 \pm 29.4$ (165 – 266)	0.88	< 0.01
MIP (cmH <sub>2</sub> O)	20	$116 \pm 6.2$ (102 – 127)	$113 \pm 4.1$ (104 – 123)	0.76	< 0.01
<u>10 km Water TT</u>					
Time (min:s)	14	$46:10 \pm 03:08$ (42:11 – 53:34)	$46:23 \pm 03:16$ (43:03 – 53:55)	0.95	< 0.01



**Figure 3:** Scatter plot of the distance (m) covered during the second 30 min K1 Ergo EPT vs the first K1 Ergo EPT. (ICC: Intraclass correlation coefficient, solid line: regression line)

#### D. PREDICTORS OF KAYAK ENDURANCE PERFORMANCE

##### 1. Predictors of kayak endurance performance in the laboratory (30 min K1 Ergo EPT)

All the kinanthropometric measurements, the outcome variables of the maximum aerobic capacity test, respiratory muscle function tests and the core stability index of the total group ( $n = 20$ ) were tested for their association with the average PO of the 30 min K1 Ergo EPT.

Although all possible correlations were calculated, only the statistically significant results are given. Amongst the kinanthropometric variables, wrist girth showed the strongest correlation ( $r = 0.60, P < 0.01$ ) with the average PO during the 30 min K1 Ergo EPT. Low, but significant correlations were also found for sitting height ( $r = 0.45$ ), arm length ( $r = 0.44$ ) and arm span ( $r = 0.45$ ) (All  $P < 0.05$ ), but not back stroke length.

Three respiratory muscle function variables correlated significantly with the average PO during the 30 min K1 Ergo EPT. MVV showed a moderate correlation coefficient of  $r = 0.61$  ( $P < 0.01$ ), while PEF showed a significant but weaker correlation ( $r = 0.54$ ,

$P < 0.05$ ) with the average PO during the 30 min K1 Ergo EPT. Respiratory muscle strength, assessed as the best MIP achieved by subjects, correlated moderately with endurance performance in the laboratory ( $r = 0.57$ ,  $P < 0.05$ ).

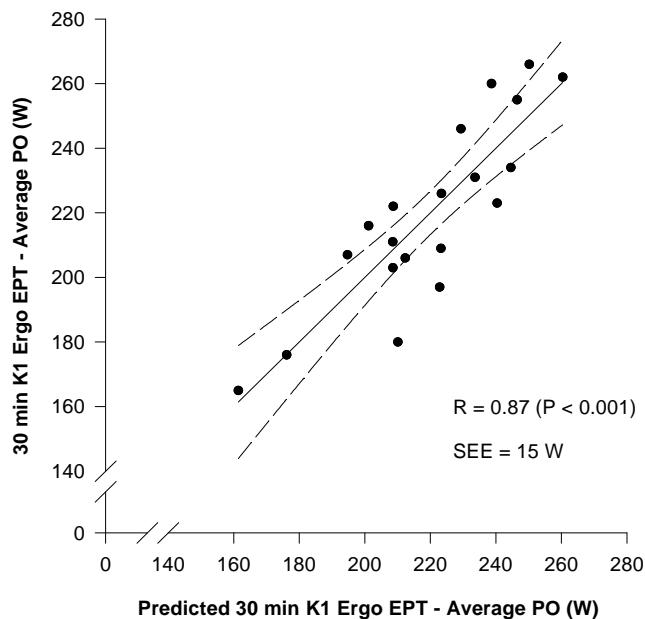
Two maximum aerobic capacity variables revealed highly significant correlations with the average PO during the 30 min K1 Ergo EPT. Both PPO and time to exhaustion revealed strong relationships with the performance test ( $r = 0.80$  and  $0.78$ , respectively,  $P < 0.01$ ). There was a low, but significant correlation between absolute  $\text{VO}_{2\text{max}}$  and endurance performance in the laboratory ( $r = 0.54$ ,  $P < 0.05$ ). There was no relationship between the core stability index and the 30 min K1 Ergo EPT.

**Table 14:** Multiple regression analysis for predicting 30 min K1 Ergo EPT performance.

Variable	R	$R^2$	$R^2$ adjusted	$\Delta R^2$	SEE	P value
PPO (W)	0.80	0.63	0.61	0.63	17.90	< 0.001
PPO (W) & MVV ( $\text{L} \cdot \text{min}^{-1}$ )	0.87	0.75	0.72	0.12	15.15	< 0.001

R: multiple correlation coefficient,  $R^2$ : coefficient of determination,  $R^2_{\text{adjusted}}$ : adjusted coefficient of determination,  $\Delta R^2$ : change in the coefficient of determination, SEE: standard error of estimate, P value: level of significance.

Stepwise multiple regression analysis revealed a significant multiple correlation coefficient of  $R = 0.87$ . Only PPO and MVV significantly predicted 30 min K1 Ergo performance. PPO, achieved during the maximum aerobic capacity test, accounted for 63% ( $R^2_{\text{adjusted}} = 61\%$ ) of the variance in 30 min K1 Ergo performance, followed by MVV that accounted for an additional 12% ( $R^2_{\text{adjusted}} = 72\%$ ) of the variance in 30 min K1 Ergo performance. These two variables predicted the average PO during the 30 min K1 Ergo EPT with an error of 15 W (Fig. 4). No other variable contributed significantly to the prediction of the 30 min K1 Ergo performance.



**Figure 4:** Scatter plot of the measured vs the predicted average PO during the 30 min K1 Ergo EPT. (R: multiple correlation coefficient, SEE: standard error of the estimate, solid line: regression line, dotted line: 95 % confidence intervals)

The resulting regression equation to predict average PO during the 30 min K1 Ergo EPT from PPO and MVV was:

$$\text{Avg PO (30 min EPT)} = (0.70 \times \text{PPO}) + (0.31 \times \text{MVV}) - 35.1 \dots \text{eq. 8.1,}$$

where Avg PO (30 min EPT) is the average power output in Watt during the 30 min K1 Ergo EPT, PPO is the peak power output in Watt and MVV is maximum voluntary ventilation in  $\text{L} \cdot \text{min}^{-1}$ .

## 2. Predictors of kayak endurance performance in the field (10 km water TT)

The outcome variables from the kinanthropometric assessment, maximum aerobic capacity test, respiratory muscle function tests, the core stability index and the 30 min K1 Ergo EPT of 14 subjects, who completed the 10 km water TT, were tested for associations with 10 km performance time.

Figures 5 (A) to (F) illustrates the significant relationships of the different outcome variables that correlated with the 10 km water performance time (s). MIP was the only respiratory muscle function variable that significantly correlated with 10 km performance time (Fig. 5A). Almost all the maximum aerobic capacity outcome variables showed moderate, but significant correlations with 10 km performance time. The strongest correlation was between relative  $\text{VO}_{2\text{max}}$  and 10 km performance time (Fig. 5C). PPO (Fig. 5D) and time to exhaustion (Fig. 5E) correlated moderately with 10 km performance time, respectively.

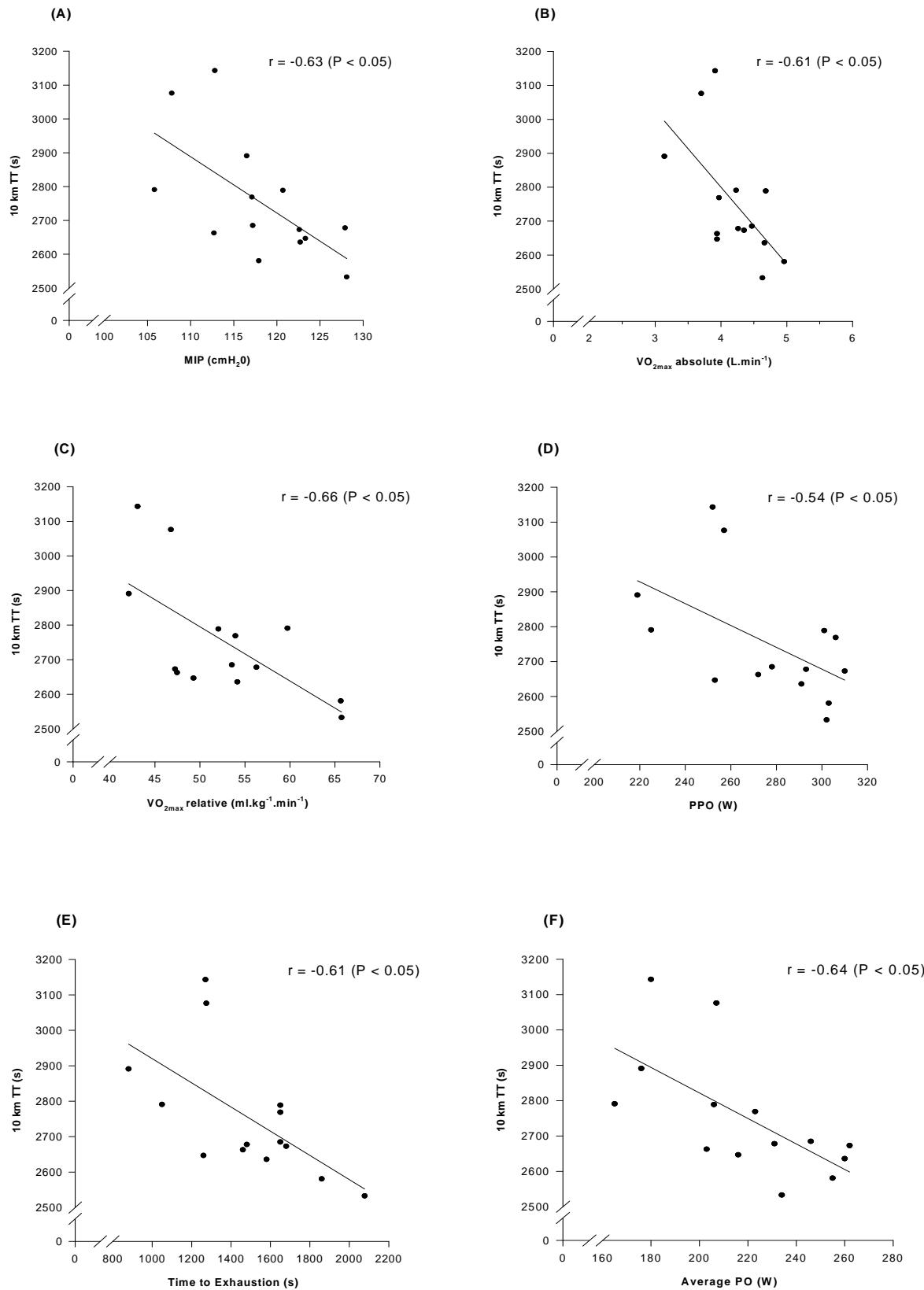
The 30 min K1 Ergo EPT in the laboratory revealed a significant relationship with the 10 km TT on the water. Average PO correlated moderately with 10 km performance time (Fig. 5F). None of the kinanthropometric variables, or the core stability index correlated with 10 km performance time.

**Table 15:** Multiple regression analysis for predicting 10 km water TT performance.

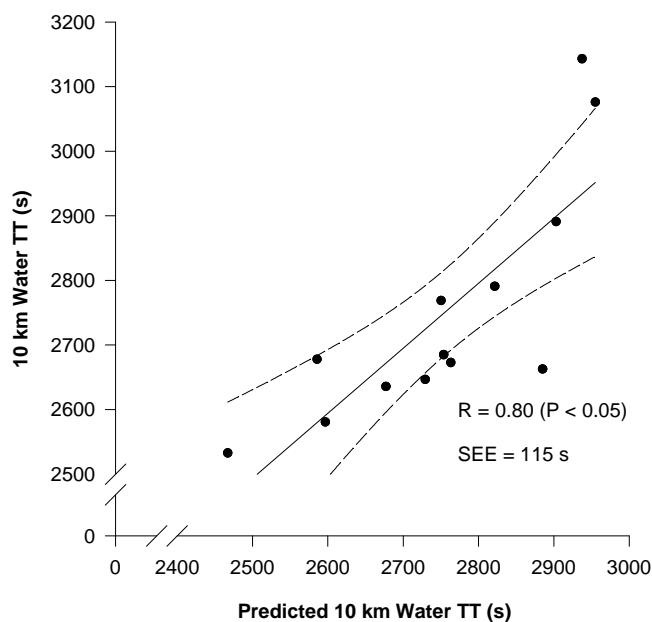
Variable	R	$R^2$	$R^2_{\text{adjusted}}$	$\Delta R^2$	SEE	P value
$\text{VO}_{2\text{max}} (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$	0.66	0.43	0.38	0.43	138.77	$\leq 0.01$
$\text{VO}_{2\text{max}} (\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1})$ & Best MIP ( $\text{cmH}_2\text{O}$ )	0.80	0.64	0.58	0.21	115.19	< 0.005

R: multiple correlation coefficient,  $R^2$ : coefficient of determination,  $R^2_{\text{adjusted}}$ : adjusted coefficient of determination,  $\Delta R^2$ : change in the coefficient of determination, SEE: standard error of estimate, P value: level of significance.

Stepwise multiple regression analysis revealed a significant multiple correlation coefficient of  $R = 0.80$  and a standard error of the estimate of 115.19 to predict 10 km TT (time in s) (Fig. 6). Relative  $\text{VO}_{2\text{max}}$  and MIP were the only two outcome variables which significantly predicted 10 km performance time. Relative  $\text{VO}_{2\text{max}}$  accounted for 43% ( $R^2_{\text{adjusted}} = 38\%$ ) of the variance in the 10 km performance time and best MIP accounted for an additional 21% ( $R^2_{\text{adjusted}} = 58\%$ ) of the variance. No other outcome variables contributed significantly to the prediction of 10 km performance time.



**Figure 5:** Relationships between various outcome variables and 10 km performance time: (A) MIP, (B) VO<sub>2max</sub> absolute, (C) VO<sub>2max</sub> relative, (D) PPO, (E) Time to exhaustion, (F) Average PO. ( $r$ : Pearson correlation coefficient, solid line: regression line)



**Figure 6:** Scatter plot of the measured vs the predicted performance time of the 10 km water TT.  
(R: Multiple correlation coefficient, SEE: standard error of the estimate, solid line: regression line, dotted line: 95 % confidence intervals)

The resulting regression equation to predict the time for the 10 km water TT from relative  $\text{VO}_{2\text{max}}$  and best MIP was:

$$\text{Time (10 km TT)} = 4885 - (12.26 \times \text{Rel VO}_{2\text{max}}) - (12.59 \times \text{best MIP}) \dots \text{eq. 8.2,}$$

where Time (10 km TT) is the time to complete the 10 km time trial in s, Rel  $\text{VO}_{2\text{max}}$  is the relative maximum oxygen consumption in  $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and best MIP is the highest maximum inspiratory mouth pressure in  $\text{cmH}_2\text{O}$ .

## **CHAPTER NINE**

### **DISCUSSION**

#### **A. INTRODUCTION**

Due to a lack of studies on kayak endurance paddlers most results of the present study were compared to the findings of studies on kayak sprint paddlers. Due to the different physical and physiological requirements of sprint and endurance events, contradictory outcomes between the present study and previous studies were expected. In general, the differences between sprint and endurance events are known for other sports (cycling, running), but very little is known about the differences, if any, between kayak sprint and endurance events. Therefore, the comparisons between this study (endurance paddlers) and previous studies (sprint paddlers) are novel and will provide insight into the different requirements for sprint and endurance kayak events.

#### **B. KINANTHROPOMETRY**

##### **1. Differences in kinanthropometry between competitive paddlers**

Sitting height relative to stature was significantly greater in the Elite paddlers compared to the Sub-Elite paddlers (Table 2). This finding is in agreement with Fry & Morton (1991), who reported that selected provincial paddlers had significantly greater values for sitting height compared to non-selected provincial paddlers. Cermak et al. (1975) also found that the sitting height of paddlers ( $n = 17$ ) were 3.4% greater than the sitting height of non-paddlers ( $n = 72$ ). Only, Van Someren & Palmer (2003) found no significant differences in sitting height between international and national level paddlers. The possible answer to the different outcomes may lie in the type of paddlers included in the studies. Only Van Someren & Palmer (2003) studied exclusively sprint paddlers (200 m). The other studies involved mixed groups of both sprint and endurance paddlers (500 m to 42 km), including this study that was limited to endurance paddlers. It seems therefore that sitting height may be a contributing factor to success in kayak endurance events, but less so in kayak sprint events. The reason for this finding is not obvious.

The major finding in the literature is that successful paddlers exhibit greater upper body characteristics than less successful paddlers (Fry & Morton, 1991; Van Someren & Palmer, 2003). This finding is also consistent with other studies reporting the characteristics of elite sprint paddlers (500 m and 1000 m) (Cermak et al., 1975; Misigoj-Durakovic & Heimer, 1992; Sidney & Shephard, 1973; Tesch, 1985). It is therefore clear that paddlers competing over sprint distances require great upper body muscularity for kayak success. However, in this study no differences were found in upper body characteristics (except for sitting height relative to stature) between the Elite and Sub-Elite paddlers. Therefore, top level kayak endurance performance (10 km and 42 km) is not dependent on great upper body muscularity.

The kinanthropometric profile of the paddlers in the present study was compared to the paddlers of Van Someren & Palmer (2003) to determine to what extent local paddlers physically resembled international paddlers. Overall, the South African (S.A.) paddlers showed greater similarities to the national level paddlers than to the international level paddlers (Table 3). Even the Elite paddlers in this study physically resembled the national paddlers more than the international level paddlers. Thus, with regards to body shape and size, the Elite paddlers of the present study revealed inferior physical characteristics compared to the international paddlers of Van Someren & Palmer (2003), but revealed more or less the same kinanthropometric profile of the less successful (national) paddlers. A possible reason why the elite paddlers of the present study revealed a smaller body size compared to the elite paddlers of Van Someren & Palmer (2003), is that sprint events require great power, and therefore, greater upper body muscularity, whereas this requirement is less important for paddlers succeeding in kayak endurance events. In fact, it would be advantageous for endurance paddlers to be smaller and lighter, similarly to endurance runners vs sprinters.

The paddlers in this study (Elite as well as Sub-Elite) revealed a somatotype classification of a balanced mesomorph. This is in accordance with the results of Van Someren & Palmer (2003). Therefore, despite some differences in kinanthropometric attributes, it seems that endurance paddlers and sprint paddlers overall have the same somatotype.

## **2. Correlations between kinanthropometry and performance**

Three upper body length measures, namely, sitting height, arm length and arm span, correlated significantly with the average PO during the 30 min K1 Ergo EPT. However, none of these upper body linear measures or wrist girth significantly predicted average PO on the K1 Ergo. None of the kinanthropometric variables correlated with the 10 km water performance time. This finding shows that greater upper body lengths give certain paddlers a biomechanical advantage over others to perform better on the K1 Ergo, but are of no significance when paddling on the water. It suggests that the paddling action on the K1 Ergo may be more dependent on biomechanical factors (i.e. leverage system formed by the arms and the paddle, back stroke length and paddling style) which may influence the generation of power, but this is not the case on the water. Other factors, which cannot be tested in the laboratory, may influence performance on the water, i.e. the paddling action through the water, race tactics, the ability to “read” water, the environment and decision making.

None of the kinanthropometric variables significantly predicted performance on the water. This finding is in agreement with Olivier & Coetzee (2002), who found no significant correlations between stature, body mass, and arm span, and 7 km race times on the water. A limitation of the latter study was that only these three kinanthropometric variables were measured, therefore it is unknown whether other variables (i.e. sitting height, arm length, etc.) might have correlated with 7 km performance time.

Van Someren & Palmer (2003) found that humerus breadth was the only variable in their test battery that significantly predicted 200 m race times ( $R^2 = 0.54$ , SEE = 0.52 sec), while Fry & Morton (1991) found significant correlations between a variety of kinanthropometric variables and 10 km and 40 km performance times on the water, respectively. However, they did not report whether any of these variables significantly predicted either 10 km or 42 km race times. The fact that these paddlers were also primarily sprint paddlers and not exclusively endurance paddlers, as in this study, can be the reason why they found significant relationships between kinanthropometry and race times and the present study did not. Another reason may be that the paddlers of the present study were too homogeneous to reveal significant correlations, while Fry & Morton (1991) tested paddlers over a wider range of abilities (7 selected state paddlers and 31 non-selected state paddlers).

The results of this study therefore show that kinanthropometric characteristics are not predictors of kayak endurance performance. It may influence performance on the K1 Ergo due to the greater emphasis on proper biomechanics to generate maximal power on the ergometer. However, in terms of endurance performance on the water, physical characteristics are probably less important.

## C. KAYAK MAXIMUM AEROBIC CAPACITY

### 1. Differences in maximum aerobic capacity between competitive paddlers.

The successful paddlers in this study had significantly higher values for relative  $\text{VO}_{2\text{max}}$ , PPO and PPO to weight ratio compared to the less successful paddlers (Table 6). These differences in the outcome variables of incremental testing are partly supported by Fry & Morton (1991), although they found differences in absolute  $\text{VO}_{2\text{max}}$  and time to exhaustion between successful and less successful paddlers. In contrast to these findings Van Someren & Palmer (2003) found no significant differences in any of the maximum aerobic capacity variables between their successful and less successful paddlers. Both Van Someren & Palmer (2003) and Fry & Morton (1991) did not report PPO to weight ratios and Fry & Morton (1991) also did not report PPO during incremental testing.

From the above three studies one can conclude that the results for maximum aerobic capacity are not important factors to distinguish between successful and less successful paddlers in kayak sprint events (Van Someren & Palmer, 2003). The fact that Fry & Morton found significant differences can be explained by the fact that their paddlers were successful over both sprint and endurance distances i.e. a mixed group. Their sample thus consisted of paddlers over a wider range of abilities (7 selected state paddlers and 31 non-selected state paddlers). However, with the assessment of endurance paddlers, exclusively, the results of maximum aerobic capacity are recognized as factors to distinguish between successful and less successful endurance paddlers.

Other reasons that could have influenced the results, include the differences in the test protocols and types of apparatus to achieve maximum aerobic capacity. All three studies used different protocols and Fry & Morton (1991) did not use the K1 Ergo, but a modified cycle ergometer mounted on a kayak frame.

The cardiorespiratory characteristics of the total group of paddlers were compared to the international and national level paddlers of Van Someren & Palmer (2003), in order to rate the local paddlers in terms of their cardiorespiratory fitness. The S.A. paddlers reached lower  $HR_{max}$  values, but higher PPO values compared to both the international and national level paddlers of Van Someren & Palmer (2003). This can be attributed to the different test protocols used by Van Someren & Palmer (2003) and the present study. Despite the small differences, the S.A. paddlers were very similar to the international paddlers in terms of their maximum aerobic capacities.

## **2. Correlations between maximum aerobic capacity and performance**

Although absolute  $VO_{2max}$ , PPO and time to exhaustion correlated significantly with the 30 min K1 Ergo EPT, only PPO was a significant predictor of endurance performance in the laboratory. This could be, in part, because all these variables are inter-related. Paddlers who reached the highest PPO during incremental testing, averaged the highest PO during the 30 min K1 Ergo EPT. This finding shows that power is the most important determinant of performance on the K1 Ergo in the laboratory. Although this finding is not supported by others who conducted kayak performance tests in the laboratory, previous studies only involved sprint performance tests and the relationship between  $VO_{2max}$  and performance was not studied. The results of this study are similar to that found in cycling. PPO during incremental testing on a cycle ergometer correlated highly with an endurance cycling time trial on the cycle ergometer ( $r = -0.94$ ,  $P < 0.01$ ), and was the best indicator compared to all the other measured variables during incremental testing (Bentley & McNaughton, 2003).

Absolute and relative  $VO_{2max}$ , PPO and time to exhaustion correlated significantly with the 10 km water time trial (Fig. 5B to E). Relative  $VO_{2max}$  revealed a stronger correlation ( $r = -0.66$ ) than absolute  $VO_{2max}$  ( $r = -0.61$ ) with 10 km performance time on the water. In agreement to this finding, Olivier & Coetze (2002) also found a stronger relationship between relative  $VO_{2max}$  ( $r = -0.81$ ) than absolute  $VO_{2max}$  ( $r = -0.74$ ) and 7 km race time. Fry & Morton (1991) also reported significant correlations between absolute and relative  $VO_{2max}$ , and 10 km and 42 km race times, respectively. However, relative  $VO_{2max}$  did not show stronger correlations with performances in that study. Bishop (2000) reported similar findings to the present study, but for sprint kayaking. He found a stronger correlation

between relative  $\text{VO}_{2\text{max}}$  ( $r = -0.82$ ) and 500 m race time, compared to absolute  $\text{VO}_{2\text{max}}$  ( $r = -0.72$ ).

All these results therefore indicate that weight is a determining factor for successful kayak performance, in both sprint and endurance events. Heavier paddlers will thus have a disadvantage compared to lighter paddlers, since their weight will cause the boat to sit deeper in the water, causing an increase in frictional drag, which increases the resistance that is required to be overcome to propel the kayak in a forward direction.

In contrast to the present study, both Bishop (2000) and Van Someren & Palmer (2003) found no significant relationship between PPO, achieved during the incremental test, and performance time on the water. However, Bishop (2000) also expressed PPO as a function of weight, and then found a significant association with performance time ( $r = -0.75$ ,  $P < 0.05$ ). Other studies that also found significant correlations between maximum aerobic capacity and kayak endurance events, did not report PPO during incremental testing and could therefore not correlate it with performance (Pickard & Pyke, 1981; Olivier & Coetzee, 2002; Fry & Morton, 1991). Therefore, the finding of the present study makes a valuable contribution to the literature.

In the present study, a significant correlation was also found between time to exhaustion in the incremental test and performance in the field. This finding is supported by the results of Pickard & Pyke (1981) and Fry & Morton (1991). Therefore, the paddler who sustained exercise the longest during incremental testing also achieved the best time during the 10 km race.

Despite the fact that several indices of the maximum incremental test ( $\text{VO}_{2\text{max}}$ , PPO and time to exhaustion) correlated significantly with performance on the water, it was the relative  $\text{VO}_{2\text{max}}$  that was the best predictor of 10 km race time (Fig. 6). This is in agreement with the results of Olivier & Coetzee (2002) and Fry & Morton (1991). This finding confirms that  $\text{VO}_{2\text{max}}$  obtained from the traditional incremental exercise test, still remains an important determinant of performance in the field.

The above discussion indicates clearly that the determinants for laboratory and field performance were not the same. PPO was the best predictor for kayak endurance

performance in the laboratory, while relative  $\text{VO}_{2\text{max}}$  was the best predictor for performance in the field. It is possible that the additional demands of racing on the water (i.e. environment, race tactics, etc.) are better reflected by the physiological (endurance) capacities ( $\text{VO}_{2\text{max}}$ ), compared to the upper body power of the paddlers. On the other hand one must bear in mind that performance outcomes were measured differently for the two performance tests, namely average PO for the K1 Ergo EPT in the laboratory and time for the 10 km race on the water. This factor may have contributed to the different outcomes of the multiple regression analyses.

## D. RESPIRATORY MUSCLE FUNCTION AND FATIGUE

### 1. Differences in respiratory muscle function between competitive paddlers

In accordance with the findings of Van Someren & Palmer (2003), there was no significant difference in FVC (Table 11) between the Elite and Sub-Elite paddlers in this study. Fry & Morton (1991), however, found a significantly higher FVC in selected provincial paddlers compared to non-selected provincial paddlers. This finding can probably be attributed to the significant difference in stature between their two groups ( $180 \pm 5$  vs  $175 \pm 5$  cm). It seems therefore that lung capacity measured as FVC, is not an important factor to distinguish between successful and less successful paddlers.

The South African (S.A.) paddlers in this study had superior lung capacities compared to the national paddlers of Van Someren & Palmer (2003), but similar lung capacities compared to the international paddlers. The local paddlers also showed superior values for pulmonary function compared to competitive paddlers from other studies (Sidney & Shephard, 1973; Misigoj-Durakovic & Heimer, 1992; Fry & Morton, 1999). It is possible that the differences in lung capacities are due to differences in stature, with the S.A. paddlers being taller than most other paddlers reported on in the literature. Since stature is one of the most important determinants of lung function, this would be a logical explanation. On the other hand it is possible that the superior lung functions of the S.A. paddlers can be attributed to the effects of long term endurance training. The positive effects of regular endurance training are supported in the literature where significantly greater lung capacities were observed for athletes compared to sedentary individuals (Kaufmann et al., 1974; Bertholon et al., 1986; Pherwani et al., 1989; Lakhera et al., 1994). Significant increases in lung capacities have

been found after a 20 week walk-run training programme (40 min per day, 3 times per week) in 12 previously sedentary individuals (Robinson & Kjeldgaard, 1982) and after 6-8 months of regular training in 9 adolescent rowers compared to 13 controls (Bertholon et al., 1986).

The Elite paddlers showed significantly greater respiratory muscle strength (MIP) compared to the Sub-Elite paddlers (Table 11). Although Coast et al. (1990) found no significant differences in MIP between competitive skiers and sedentary college students, the students showed large inter-individual variation in MIP (CV = 11%). This, together with a small sample size (6 skiers and 5 students) may have resulted in the non-significant results.

Despite these findings, it is still unclear whether competitive athletes have greater respiratory muscle strength compared to moderately active or even sedentary individuals. The respiratory muscle strengths of the S.A. paddlers ( $118 \pm 5.7$  cmH<sub>2</sub>O) were less than for healthy men (Loke et al., 1982), moderately trained men (McConnell et al., 1997), rowers (Volianitis et al., 1999; Volianitis et al., 2001) and competitive cyclists (Romer et al., 2002). On the other hand, higher MIP values were obtained for the S.A. paddlers compared to ultra-marathon runners (Ker & Schultz, 1996) and competitive swimmers (Lomax & McConnell, 2003). The S.A. paddlers' mean age and height differed from the above studies, but there was no clear pattern that showed that younger or taller groups had higher MIP values. The differences in height can be attributed to the fact that females were also included in the subject groups of the other studies. However, it was clear from the literature review that there is no consistency in the measurement of respiratory muscle strength. Not only are different devices used to measure MIP, but there are also huge variations in the test protocols and the criteria to establish the highest (maximal) inspiratory pressure.

## **2. Correlations between respiratory muscle function and performance**

Several respiratory indices (PEF, MVV and MIP) correlated significantly with 30 min K1 Ergo performance. Of those, MVV was the second best predictor (after PPO) for kayak endurance performance in the laboratory. This is a novel finding, since no other studies on kayaking have investigated the relationships between RM function and kayak endurance performance in the laboratory. The fact that significant differences were found in MVV between the successful and less successful paddlers of this study, emphasizes the importance

of respiratory muscle endurance as a determinant of successful kayak endurance performance in the laboratory.

In contrast to the above findings, 10 km race time on the water was more dependent on respiratory muscle strength (MIP). Multiple regression analysis showed that MIP, together with relative  $\text{VO}_{2\text{max}}$ , were the best predictors of performance on the water. As previously indicated, this is a novel finding which has not been reported previously. Fry & Morton (1991) found significant correlations between FVC and 4 different race distances. As the race distance increased (500 m, 1000 m, 10 km and 42 km), the association with performance became stronger ( $r = -0.39$ ,  $-0.37$ ,  $-0.56$  and  $-0.70$ , respectively). Van Someren & Palmer (2003), who investigated sprint kayaking, found no relationship between any of the pulmonary function variables and 200 m race times. It can therefore be concluded that RM function plays a determining role in successful endurance performance, but is probably less important in successful sprint kayaking.

### **3. Respiratory muscle fatigue after the 30 min K1 Ergo EPT**

In recent years the observation of respiratory muscle fatigue after exercise (Loke et al., 1982; Bye et al., 1984; Bender & Martin, 1985; Ker & Schultz, 1996; McConnell et al., 1997) questioned the historical belief that the respiratory system is “over-built” for the demands placed upon it by exercise and is thus not recognized as a limiting factor of athletic performance. However, the implication of respiratory muscle fatigue is that it can limit athletic performance, as shown by studies that induced RM fatigue prior to exercise (Martin & Stager, 1981; Mador & Acevedo, 1991). Therefore, the determination of RM fatigue is of practical relevance, since athletes can improve their RM function through specialized RM training, which may lead to an improvement in performance. Recently, two studies have shown that RM training improved athletic performance (Volianitis et al., 2001; Romer et al., 2002).

In this study no RM fatigue, measured as a decrease in MIP, was found after the 30 min K1 Ergo EPT in the laboratory (Fig. 2). The first EPT caused a mean decrease of 0.7% in MIP, while the second EPT caused a mean increase of 4.5% in MIP. These results contradict previous findings where RM fatigue was reported after various endurance performance tests

or events (Loke et al., 1982; McConnell et al., 1997; Volianitis et al., 1999; Volianitis et al., 2001; Romer et al., 2002).

The most relevant finding among previous studies on RM fatigue is the study of Volianitis et al. (2001), who investigated RM fatigue after rowing performance (upper body exercise). They found a significant decrease in MIP (11%) after a 6 min all-out rowing test in well-trained, competitive rowers. It can be argued that the most obvious explanation of the contradictory findings of the present study with the findings of Volianitis et al. (2001), is that different types of performance tests were used to induce fatigue (short, high intensity exercise vs prolonged endurance exercise). Although only limited studies have been done in this regard, it seems that RM fatigue is not limited to sprint-type exercise. Romer et al. (2002) found significant decreases of 18% and 13% in MIP after 20 km ( $29.6 \pm 0.5$  min) and 40 km ( $59 \pm 1.5$  min) cycling time trials, respectively. The occurrence of RM fatigue only after short all-out performance is therefore not a logical explanation.

Several reasons can be put forward to explain the absence of RM fatigue in the S.A. paddlers. First of all it is possible that RM fatigue is not induced during endurance tests on the K1 Ergo. Therefore, RM fatigue is not a limiting factor to kayak endurance tests in general. Secondly, the 30 min test may have been too short or of too low intensity to cause RM fatigue. However, Romer et al. (2002) reported RM fatigue in cyclists after exercise that lasted approximately 30 min.

One must also consider the reliability of the MIP measurement. In this study, the repeatability of the baseline MIP measurements was acceptable ( $ICC = 0.76$ ,  $P < 0.01$ ), and there were no significant differences in the mean values for the two baseline measurements ( $116 \pm 6.2$  vs  $113 \pm 4.1$ ,  $P > 0.05$ ) indicating only a minor learning effect. This finding is in agreement with others who used similar devices and protocols to measure respiratory muscle strength. For instance, Volianitis et al. (1999) reported non-significant differences (less than 5 cmH<sub>2</sub>O) in baseline MIP values on two separate occasions. The mean ( $\pm$  SD) coefficient of variation for the baseline MIP measured on the two occasions was 4.65 ( $\pm 0.76$ )%.. They also used the Bland-Altman plot as additional analysis for repeatability which revealed limits of agreement of  $\pm 26.6$  cmH<sub>2</sub>O. McConnell & Copestake (1999) found no significant differences between first and second MIP measurements ( $94 \pm 25.9$  vs  $97 \pm 26.3$  cmH<sub>2</sub>O,  $P > 0.05$ ), one week apart, and reported that the coefficient of reproducibility for MIP was

acceptable with 95% of the subjects generating retest pressures within 11% of initial readings. Maillard et al. (1998) measured MIP one day (session 2) and one month (session 3) after baseline measurements (session 1) in ten healthy individuals. The mean and SD of differences between sessions were calculated, and the coefficient of repeatability was computed as twice the SD. The coefficients of repeatability of MIP were 28 and 21 cmH<sub>2</sub>O between session 1 and 2, and 2 and 3, respectively. They suggested that reproducibility was not deteriorating over time, since the coefficient of repeatability was lower after one month than after one day. It is thus widely accepted that MIP measurements are a reliable method to assess RM fatigue. However, whether or not MIP is a valid method to assess RM fatigue, is still argued by some (Perret et al., 1999; Romer et al., 2002). The latter authors may be correct, since the limits of agreement above indicate that differences from pre-test to post-test measurements should be at least higher than 25 cmH<sub>2</sub>O, which is quite high.

Perret et al. (1999) compared different non-invasive methods to assess RM fatigue after cycling endurance tests to determine which test reflected RM fatigue. “Time to task failure”, which entailed the subject to achieve a predetermined target pressure with each inspiratory effort, against an inspiratory resistance, was the only method which reflected a significant decrease in RM performance after exhaustive endurance exercise. They reported that MIP (as well as the measurements of VC, FVC, FEV<sub>1</sub>, MVV and MEP) was not affected by exhaustive cycling at 85% of maximal oxygen uptake. Romer et al. (2002) reported a significant decrease in maximum inspiratory flow rate, together with a decrease in MIP, after cycling endurance tests. They suggested it is becoming increasingly important to measure changes in velocity and shortening of the respiratory muscles (quantified by maximum inspiratory flow rate) and not just the measurement of a decreased ability to produce force (quantified by MIP) to assess respiratory muscle fatigue. Both “time to task failure” and maximum inspiratory flow rate depict changes in velocity and shortening of the respiratory muscles, which cannot be measured by MIP.

Thus, a limitation of this study is that it did not measure “time to task failure” or maximum inspiratory flow rate. The possibility that the paddlers developed RM fatigue must therefore not be excluded and this warrants further investigation.

## **E. PERFORMANCE TESTS IN THE LABORATORY AND FIELD**

### **1. Differences in performance tests between competitive paddlers**

The significant difference in average PO and total distance achieved between the Elite and Sub-Elite paddlers (Table 8) shows that the newly developed 30 min K1 Ergo endurance performance test (EPT) was a valid laboratory test, to distinguish between successful and less successful endurance paddlers. No other study exists to contribute to this finding, since endurance performance tests on the K1 Ergo have not yet been investigated by others.

The significant difference in average back stroke length (Table 8) during the 30 min K1 Ergo EPT, between the Elite and Sub-Elite paddlers, emphasizes the importance of biomechanical technique to endurance performance in the laboratory. Although average back stroke length did not correlate significantly with the average PO during the 30 min K1 Ergo EPT ( $r = 0.42$ ,  $P > 0.05$ ), it can still be recognized as one of the factors to differentiate successful paddlers from less successful paddlers. It can be postulated that a greater average back stroke length is the direct result of greater upper body lengths (sitting height relative to stature) and upper body length measures (sitting height, arm length, arm span), which correlated significantly with the average PO during the 30 min K1 Ergo EPT.

The significant difference in mean 10 km performance time on the water between the Elite and Sub-Elite paddlers (Table 9) is supported in the literature by Fry & Morton (1991) who found significant differences between their two ability groups for 10 km performance time ( $2731 \pm 104$  vs  $2999 \pm 197$  s,  $P < 0.01$ ). Therefore, the 10 km water time trial can be recognized as a valid test to differentiate between different levels of paddlers, despite the fact that race distances could be as high as 42 km.

The paddlers of the present study showed faster times for the 10 km water time trial ( $2650 \pm 78$  s) compared to both groups of Fry & Morton (1991). These faster times could be attributed to the fact that the paddlers of the present study were superior in their kayak endurance performance abilities compared to the selected and non-selected provincial paddlers of Fry & Morton (1991). However, caution must be taken in this conclusion, since the 10 km distances on the water were not conducted on the same routes or on the same day,

or under the same weather conditions. All of these factors could have influenced the final outcomes.

A limitation of this study was the use of different routes at the three different clubs where paddlers performed their individual 10 km time trials. The time trials were also conducted on different days with varying weather conditions. Despite these confounding factors, the 10 km water time trial revealed a high intraclass correlation coefficient for repeatability of  $r = 0.95$  ( $P < 0.01$ ). This high reliability result shows that the weather conditions did not have a major influence on 10 km performance time. Whether paddlers would have performed differently if they have been tested on the same route is inconclusive, but this may explain, in part, the relatively weak, though still statistically significant correlations presented in Fig. 5.

## **2. The relationship between the 30 min K1 Ergo EPT and the 10 km water TT**

The average PO during the 30 min K1 Ergo EPT correlated significantly with 10 km performance time on the water (Fig. 5 F). No other study in the literature has investigated the relationship between endurance performance in the laboratory and performance on the water. However, this phenomenon has been investigated in kayak sprint performance with contradictory outcomes. Bishop (2000) found no significant relationship between a 2 min sprint on the K1 Ergo and 500 m race time, whereas Van Someren & Palmer (2003) found a significant correlation between total work done during the 30 s sprint test and 200 m race time. The non-significant results from Bishop's study are probably related to the very small sample size (9 paddlers), who were also very similar in their kayak performance abilities.

One of the aims of the study was to determine if the 30 min K1 Ergo EPT can be used as a standardized test to assess kayak endurance performance in the laboratory. For this purpose, the K1 Ergo test must prove to be both reliable and valid.

The repeatability of average PO during the K1 Ergo EPT was highly significant ( $ICC = 0.88$ ,  $P < 0.01$ ). This implied that within one week, the paddler's performance on the K1 Ergo were consistent between the first and second tests. Furthermore, the significant correlation between average PO and 10 km race time ( $r = -0.64$ ,  $P < 0.05$ ) confirmed the validity of the test. Therefore, the 30 min K1 Ergo EPT can be considered a valid and reliable test to

evaluate kayak endurance performance in the laboratory. This finding is supported by similar studies on sprint kayaking and endurance cycling, respectively. These studies also found that performance tests in the laboratory were highly reliable (Van Someren & Dunbar, 1997; Bishop, 1997) and valid (Van Someren et al., 2000; Coyle et al., 1991).

Another finding which confirmed the validity of the 30 min K1 Ergo EPT, was the heart rate measured during both endurance performance trials (laboratory and field). Average HR during the 30 min K1 Ergo EPT produced a significant correlation coefficient of 0.79 with average HR during the 10 km water time trial ( $P < 0.01$ ). This result indicates that the two tests required similar aerobic efforts according to the heart rate.

#### F. CORE STABILITY

No significant differences were found in any of the six core stability tests and the core stability index, between the Elite and Sub-Elite paddlers. One reason for these non significant findings is the very large inter-individual variations for the individual tests. Although a few studies mentioned that core stability (or balance) can influence kayak performance (Pickard & Pyke, 1981; Bishop, 2000; Olivier & Coetzee, 2002), it has not been scientifically investigated before. Water creates an unstable environment in which the paddler needs to propel the kayak in a forward direction in the most effective and efficient way possible. Therefore, the paddler needs good core stability to balance himself in the kayak while paddling on the water. Good core stability will prevent uneconomical movements as a result of poor balance. Good core stability will also provide the paddler with a stable base against which his muscles can work to create a more powerful and efficient paddling stroke. Once the core stability of a paddler is identified as a weakness, it can then be improved through specialized core stability training, which may possibly improve kayak performance. Furthermore, no significant relationships were found between core stability and both the 30 min K1 Ergo EPT and the 10 km water TT.

The suggestion of our findings that core stability does not influence kayak endurance performance is not conclusive, since the main concern with the core stability tests were the reliability of these tests. The repeatability of the six core stability tests was investigated on gymnasts. Test one ( $n = 13$ ), two ( $n = 6$ ) and six ( $n = 6$ ) showed highly significant test-retest correlation coefficients (ICC) of  $r = 0.92$  ( $P < 0.05$ ),  $0.97$  ( $P < 0.05$ ), and  $0.94$  ( $P < 0.05$ ),

respectively. Test three ( $n = 13$ ) and test five ( $n = 6$ ) showed moderately significant ICC's of  $r = 0.79$  ( $P < 0.05$ ) and  $0.81$  ( $P < 0.05$ ), and test 4 revealed a very poor non-significant ICC of  $r = 0.26$  ( $P > 0.05$ ). The poor repeatability of test four can be one of the reasons why the core stability index showed no association with kayak performance in the laboratory and in the field.

It is also not clear whether these core stability tests assess "the ability to stabilize in the kayak". In other words, it is unknown whether the tests were specific enough and required the stabilizing muscles to recruit in the same manner and/or required the same proprioceptive patterns than during stabilization in the kayak. Due to the poor reliability of one of the individual core stability tests and the unknown validity of the core stability tests, no clear conclusion can be made to what extent core stability might or might not influence kayak performance. A limitation of the study was the lack of a standardized test to assess core stability in specifically, paddlers. This is also true for other sports.

## **G. MAIN FINDINGS**

The most important finding of this study is that relative  $\text{VO}_{2\text{max}}$  and PPO during incremental testing, and MVV and MIP during RM function testing were the most relevant attributes for success in kayak endurance performance. The measurements of relative  $\text{VO}_{2\text{max}}$ , PPO, MVV and MIP succeeded in differentiating successful paddlers from less successful paddlers. These variables (except for MVV which only correlated with average PO during the 30 min K1 Ergo EPT) significantly correlated with both the 30 min K1 Ergo EPT and the 10 km water TT, respectively.

Of these significant correlations with endurance performance, PPO and MVV significantly predicted the average PO during the 30 min K1 Ergo EPT ( $R = 0.87$ , SEE = 15 W). PPO accounted for 63% of the variance in average PO and MVV accounted for an additional variance of 12%. The present study could not identify the factors that accounted for the remaining 25% of variance in the laboratory performance test. Kayaking can be seen as a multi-skilled activity and is influenced by factors such as pacing and technical factors (e.g. paddling style), which are difficult to measure. It is likely that these factors contribute significantly to the variance in actual performance.

Relative  $\text{VO}_{2\text{max}}$  and MIP significantly predicted 10 km race time on the water ( $R = 0.80$ , SEE = 115 s). Relative  $\text{VO}_{2\text{max}}$  accounted for 43% of the variance and MIP accounted for 21% of additional variance in 10 km performance time. This leaves 36% of the variance in 10 km performance time unexplained. No other variables contributed further to the variance in 10 km race time.

Thus, the variables measured in the present study explained the variance in the laboratory performance test better than the variance in performance on the water (25% compared to 36% unexplained). Thus, the main finding of the present study was that the assessment of maximum aerobic capacity (relative  $\text{VO}_{2\text{max}}$  and PPO) and respiratory muscle function (MVV and MIP) in endurance paddlers can be recognized as the most relevant tests to identify and differentiate between paddlers for kayak endurance success.

The second most important finding was that RM fatigue was not induced by the 30 min K1 Ergo EPT. Whether RM fatigue, in actual fact, did not occur or whether the method to assess RM fatigue was lacking in specificity and sensitivity, remains inconclusive.

Other important findings were that power played a greater role in the prediction of performance in the laboratory, while relative  $\text{VO}_{2\text{max}}$  determined performance on the water. It is speculated that this difference is a reflection of factors that are controllable and uncontrollable in the laboratory and field. However, body weight becomes an additional determining factor for success when performance is measured on the water. This is evident from the fact that only absolute  $\text{VO}_{2\text{max}}$  correlated with performance on the K1 Ergo, but both absolute and relative  $\text{VO}_{2\text{max}}$  correlated with performance on the water. Relative  $\text{VO}_{2\text{max}}$  showed a stronger relationship with performance on the water compared to absolute  $\text{VO}_{2\text{max}}$ . This illustrates the difference in requirements for success in the laboratory and on the water. On the K1 Ergo, weight will not be a determining factor that influences performance, because there is no boat that needs to sit in the water. On the water, however, the lightest paddler will have the least resistance to overcome, whereas in the laboratory it is possible that the larger paddler have an advantage since performance was determined from absolute average PO over 30 min.

Another finding worth mentioning, is that sitting height relative to stature was the only kinanthropometric variable to differentiate between successful and less successful paddlers

on the basis of cross-sectional comparison between the two groups. It is postulated that the greater sitting height, in conjunction with the upper body length measures which significantly correlated with endurance performance in the laboratory, accounted for a greater average back stroke length and that this influenced the generation of PO on the K1 Ergo. Thus, successful performance on the K1 Ergo is influenced by anthropometrical factors.

No other kinanthropometric variable or measures of core stability were important determinants of endurance performance. However, this finding does not mean that core stability is unimportant.

#### **H. FUTURE STUDIES**

It is recommended that a more thorough investigation should be made of respiratory muscle fatigue and kayak endurance performance, since MVV and MIP significantly correlated and successfully predicted kayak endurance performance in the laboratory and in the field. It is suggested that not only MIP, but “time to task failure” and maximum inspiratory flow rate should also be included in the assessment to determine respiratory muscle fatigue, since MIP alone may not be specific enough to identify respiratory muscle fatigue.

The need exists for the development of a practical, standardized core stability test battery to assess the paddler’s ability to stabilize him- or herself in the kayak, since balance in the boat is critical for optimal performance. The acceptance of a standardized test to assess maximum aerobic capacity on the K1 Ergo worldwide is also recommended in order to make valid comparisons between international paddlers. Due to the high reliability and validity of the 30 min K1 Ergo EPT, it is recommended that this test is used in the future as an endurance performance test in the laboratory in order to determine the physiological responses to kayak endurance exercise. However, a method to incorporate the negative influence of body mass in the water into laboratory predictive tests should be investigated.

Future studies should also search for other factors, not identified in the present study, that may influence endurance performance in the multi-skilled sport of kayaking in order to fully understand the physical, physiological and biomechanical requirements for kayak endurance success.



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## **APPENDIX A**

### **THE CONSENT FORM**

#### **INFORMED CONSENT**

**Title of the research project:** "The relationship between respiratory muscle fatigue, core stability, kinanthropometric attributes and endurance performance in competitive kayakers."

**Reference number:** \_\_\_\_\_.

#### **STATEMENT BY KAYAKER:**

I, the undersigned,

\_\_\_\_\_ [ID] \_\_\_\_\_,  
of (address) \_\_\_\_\_  
\_\_\_\_\_

#### **confirm that:**

1. I was invited to participate in the abovementioned research project that is undertaken by the Division of Medical Physiology at the University of Stellenbosch.
2. It was explained to me that
  - 2.1 the aim of the study is to determine the relationship between respiratory muscle fatigue, trunk stability and kayak endurance performance.
  - 2.2 from the project I will receive interesting information on my general fitness level and lung functions that can be beneficial to improving my performances.
  - 2.3 I will participate in various experimental tests which will be divided into 4 respective visits to the exercise laboratory.
    - 2.3.1 I will participate in a 10 km kayak time trial on a river where I will compete with other kayakers. For this purpose I will use my own kayak, paddle and safety gear.
    - 2.3.2 my maximal aerobic capacity will be tested on the K1 ergometer. During this test the intensity of exercise will be increased every 2 minutes until I reach exhaustion. During this test oxygen uptake, breathing and heart rate will be measured.

- 2.3.3 my endurance performance will be tested on the K1 ergometer by means of a modified 6 km time trial. This test will be conducted on 2 separate days to determine the repeatability of this test.
  - 2.3.4 the exercise tests will be separated by at least 72 hours.
  - 2.3.5 my lung functions (lung volumes and airflow) will be measured with a spirometer.
  - 2.3.6. the strength and endurance of my respiratory muscles will be tested before and after the 6 km time trial tests. During these tests I will inhale against a specific resistance until cannot sustain a specific breathing rate.
  - 2.3.7 the strength and endurance of my trunk muscles will be assessed to determine core stability (ability to balance myself). These tests will consist of exercises on a gymnastics mat and a stability ball.
  - 2.3.8 my skinfolds, limb circumferences, diameters and limb lengths will be measured to determine my fat percentage and body shape/size.
3. I was warned that there is a possibility that I may experience one or more symptoms during the exercise tests on the K1 ergometer. This include dizziness, nausea, collapse, abnormally high or low blood pressure, abnormal heart rate, or shortness of breath. I understand that I may stop the exercise tests at any time when I experience any of these symptoms.
  4. the researcher/test observers and/or the University of Stellenbosch cannot be kept responsible for any injuries that might occur during any of the tests included in the project.
  5. I was informed that there will always be a medical doctor [Dr Strijdom, tel: 938-9387(w); 423-1677(h)] present at the laboratory tests and at the test on the river if any medical emergency may occur. Basic resuscitation equipment will be available in the laboratory and at the river in case of a medical emergency.
  6. I was informed that the information which will be obtained through this project will be handled confidentially, but that the results will be published in research journals.
  7. the above information was explained to me in English by \_\_\_\_\_. I was given the opportunity to ask questions and all the questions were satisfactorily answered.
  8. it was explained to me that my participation in this project is voluntary and that I may withdraw from the study at any time, without any prejudice by doing so. I also understand that the researcher or medical doctor may withdraw me from the study if deemed necessary for medical purposes.
  9. I was informed that there are no costs involved for my participation in this project.

10. I was told to inform the insurance company/companies where I hold insurance policies (if any) about my participation in this project.

**I voluntarily agree** to participate in the abovementioned project.

Signed at \_\_\_\_\_ on \_\_\_\_\_ 20 \_\_\_\_\_.  
\_\_\_\_\_  
\_\_\_\_\_

Kayaker

Witness

**STATEMENT BY RESEARCHER**

I, \_\_\_\_\_, declare that I:

1. Explained the information in this document to \_\_\_\_\_;
2. requested him to ask questions if anything was unclear;
3. that this conversation took place in English/Afrikaans.

Signed at \_\_\_\_\_ on \_\_\_\_\_ 20 \_\_\_\_\_.  
\_\_\_\_\_  
\_\_\_\_\_

Researcher

Witness

## **INGELIGTE TOESTEMMING**

**Titel van die navorsingsprojek:** "The relationship between respiratory muscle fatigue, core stability, kinanthropometric attributes and endurance performance in competitive kayakers "

**Verwysingsnommer:**\_\_\_\_\_.

### **VERKLARING DEUR KAJAKER:**

Ek, die ondergetekende

\_\_\_\_\_  
van (adres) [ID \_\_\_\_\_],  
\_\_\_\_\_  
\_\_\_\_\_

#### **bevestig dat:**

1. Ek uitgenooi is om deel te neem aan bogenoemde navorsingsprojek wat deur die Afdeling Geneeskundige Fisiologie van die Universiteit van Stellenbosch onderneem word.
2. Daar aan my verduidelik is dat
  - 2.1 die doel van die projek is om te bepaal of daar 'n verwantskap bestaan tussen asemhalingspier uitputting, romp stabiliseringsfunksie en kajak uithouvermoë prestasie.
  - 2.2 ek interessante inligting aangaande my algemene fiksheidsvlak en longfunksies uit hierdie projek sal ontvang wat my tot voordeel kan strek om my prestasies te verbeter.
  - 2.3 daar van my verwag word om verskillende eksperimentele toetse te onderneem in 4 afsonderlike besoeke aan die oefeningslaboratorium.
    - 2.3.1 'n 10 km kajak tydtoets op 'n rivier gedoen gaan word waartydens ek met ander kajakers sal meeding. Ek sal my eie kajak, roeispan en veiligheids- uitrusting gebruik tydens hierdie toets.
    - 2.3.2 my maksimale aërobiese kapasiteit getoets gaan word op die K1 ergometer wat bestaan uit oefening waarvan die intensiteit elke 2 minute verhoog word totdat ek uitgeput is. Gedurende hierdie toets sal my suurstofverbruik, asemhaling en hartspoed gemeet word.
    - 2.3.3 my uithouvermoë prestasie getoets gaan word in 'n gemodifiseerde 6 km tydtoets op die K1 ergometer. Hierdie toets sal op 'n tweede geleentheid herhaal word om die herhaalbaarheid van die toets vas te stel.
    - 2.3.4 daar 'n periode van minstens 72 uur tussen die oefeningstoetse sal wees.
    - 2.3.5 my longfunksies (longvolume en lugvloe) getoets gaan word met 'n spirometer.

- 2.3.6 die sterkte en uithouvermoë van my asemhalingspiere voor en na die 6 km tydtoetse getoets sal word. Inaseming sal plaasvind teen 'n sekere weerstand totdat ek nie meer verder die weerstand kan oorkom om in te asem nie.
- 2.3.7 die sterkte en die uithouvermoë van my rompspiere getoets gaan word om uit te vind hoe goed my romp stabiliseringsfunksie is (vermoë om myself te balanseer). Hierdie toetse behels oefeninge wat op 'n gimnastiekmat en met 'n stabiliseringsbal gedoen gaan word.
- 2.3.8 my velvoue, ledemaatomtrekke, deursnitte en ledemaatlengtes sal gemeet word om my vetpersentasie en liggaamsvorm en –grootte te bereken.
3. ek gewaarsku is dat daar 'n moontlikheid bestaan dat ek een of meer simptome tydens die oefeningstoetse op die kajak ergometer mag ondervind. Dit sluit in duiseligheid, naarheid, kollaps, abnormale hoë of lae bloeddruk, abnormale hartklop, of n toegetrekte (benoude) bors. Ek verstaan dat ek enige tyd die oefeningstoetse mag staak wanneer ek enige van hierdie simptome ondervind.
  4. die navorsers/toetsafnemers en/of die Universiteit van Stellenbosch nie verantwoordelik gehou kan word vir enige besering wat ek moontlik kan opdoen gedurende enige van die toetse ingesluit in die projek nie.
  5. ek meegedeel is dat die inligting wat ingewin word as vertroulik behandel sal word, maar dat die bevindinge wel in vaktydskrifte gepubliseer sal word.
  6. ek is ingelig dat daar altyd 'n mediese dokter by die laboratorium en by die rivier waar hierdie toetse afgeneem gaan word, [Dr. Strijdom, tel: 938-9387 (w); 423-1677 (h)] teenwoordig sal wees vir enige mediese noodgeval wat mag opduik. Daar sal basiese resussitasietoerusting in die laboratorium en by die rivier beskikbaar wees indien 'n mediese noodgeval opduik.
  7. Die inligting wat hierbo weergegee is deur \_\_\_\_\_ aan my in Afrikaans verduidelik is. Ek ook 'n geleenthed gegee is om vrae te vra en dat al my vrae bevredigend beantwoord is.
  8. Daar aan my verduidelik is dat my deelname aan hierdie projek vrywillig is en dat ek enige tyd my aan die projek mag onttrek, sonder dat ek benadeel sal word deur so te doen. Ek verstaan ook dat die navorsers of die mediese dokter my van die projek mag onttrek indien dit in my belang geag word a.g.v. medies-verwante redes.
  9. Ek is meegedeel dat daar geen koste verbonde aan my deelname is nie.
  10. Ek is versoek om die versekeringsmaatskappy(e) waar ek versekerinspolisse hou (indien enige) in te lig oor my deelname aan die projek.

**Ek stem hiermee vrywillig in** om aan die bogemelde projek deel te neem.

Geteken te \_\_\_\_\_ op \_\_\_\_\_ 20 \_\_\_\_\_.  
\_\_\_\_\_  
\_\_\_\_\_

Kajaker

Getuie

### **VERKLARING DEUR NAVORSER**

Ek, \_\_\_\_\_, verklaar dat ek:

1. Die inligting vervat in hierdie dokument aan \_\_\_\_\_ verduidelik het;
2. Hom versoek het om vrae aan my te stel indien daar enigiets onduidelik was;
3. Dat hierdie gesprek in Afrikaans plaasgevind het.

Geteken te \_\_\_\_\_ op \_\_\_\_\_ 20 \_\_\_\_\_.  
\_\_\_\_\_  
\_\_\_\_\_

Navorser

Getuie

## APPENDIX B

### ILLUSTRATIONS OF KAYAK ERGOMETRY



An illustration of the K1 Ergo interfaced with specialized computer software.

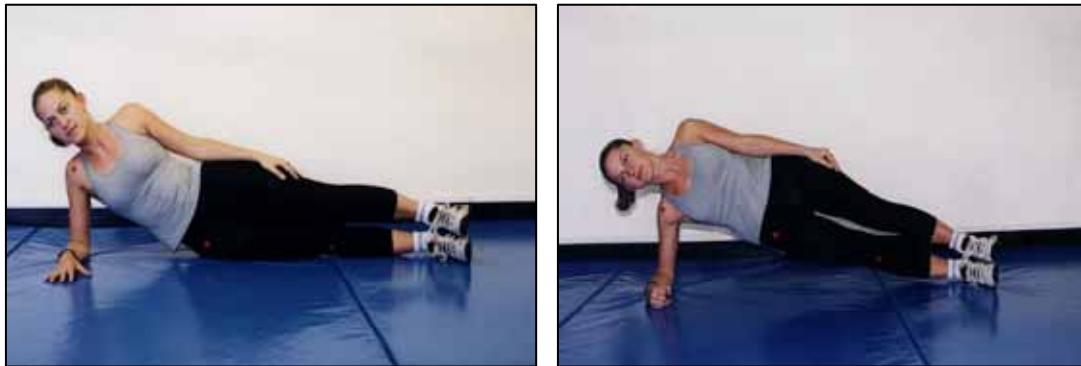


An illustration of gas sampling with a cardio-pulmonary metabolic system during incremental exercise testing.

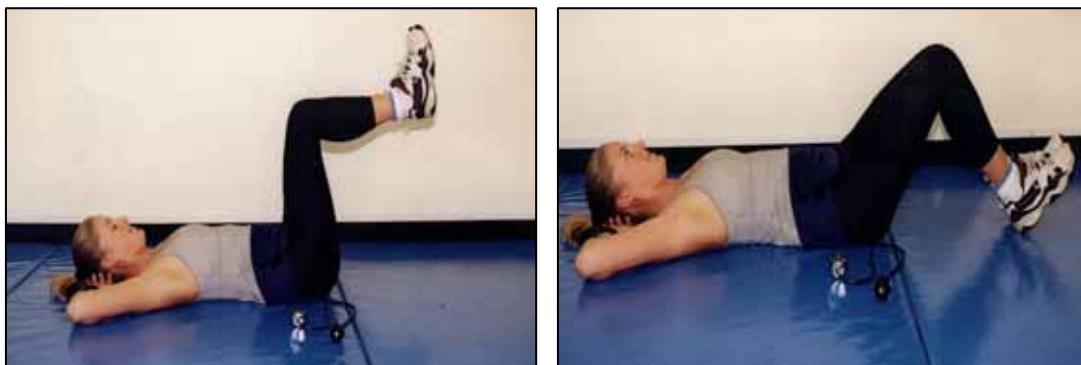
## APPENDIX C

### ILLUSTRATIONS OF THE SIX INDIVIDUAL CORE STABILITY TESTS

#### TEST ONE



#### TEST TWO



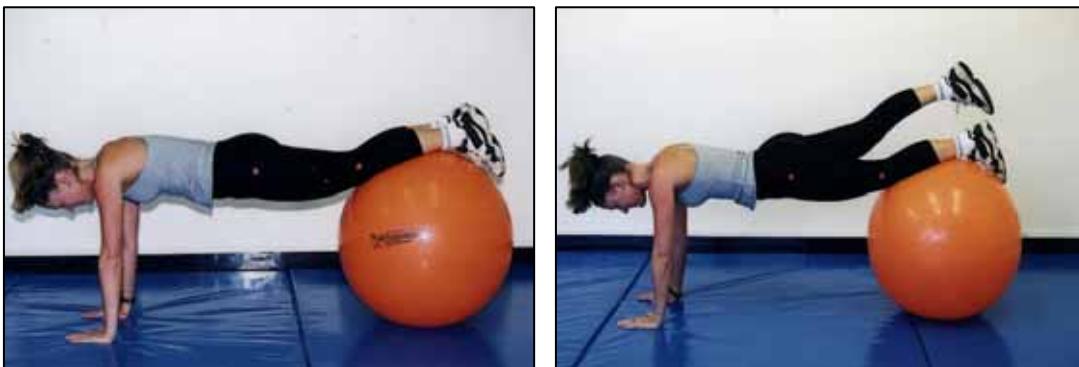
#### TEST THREE



#### **TEST FOUR**



#### **TEST FIVE**



#### **TEST SIX**

