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AN INVESTIGATION INTO DETERMINANTS OF SUCCESSFUL ROWING PERFORMANCE IN TERMS OF BODY MORPHOLOGY AND STRETCHER POSITION

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Declaration

The work described in this dissertation is my own and has not been published elsewhere. All verbatim extracts have been identified by quotation marks and a full list of references is given at the end of the text.

Morag Emery
November 2008

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Abstract

Successful rowers competing at an elite level have been shown to have particular morphological characteristics which are associated with their success (Bourgois et al. 2001; Slater et al. 2005; Kerr et al. 2007).

The aim of this investigation was to identify physical attributes which confer an advantage to 2km rowing ergometer performance in Scottish University rowers. The participants comprised 30 Open-class males, 20 lightweight males, 18 Open-class females and 4 lightweight females (including four World Class Start athletes) who were all competing for their Universities at the Championships. A secondary aim was to determine a relationship between peak acceleration in a single scull at three differing foot stretcher positions and body morphology. Six experience female scullers participated in this secondary experiment.

Rowers competing at the Scottish University Indoor Rowing Championships 2007 and 2008 were measured for 39 anthropometric dimensions using standard International Society for the Advancement of Kinanthropometry (ISAK) protocol.

Stature, muscle mass and mid thigh girth were correlated with performance in Open-Class men (p<0.05); biiliocristal breadth and humerus breadth were correlated with performance in lightweight men (p<0.05) and corrected forearm girth and sum of skinfolds were correlated with performance in females (p<0.05). After scaling for stature, distinct differences could be seen between the male and female athletes. A regression showed a relationship to exist (r²=0.64) between stature, body mass and peak acceleration in a single scull.

In conclusion, Scottish University rowers showed distinct morphological characteristics which provide a competitive advantage in 2km ergometer rowing. A relationship was also established between morphology and peak acceleration in a single scull.

Keywords: rowing, anthropometry, proportionality, somatotype, World Class Start, foot stretcher position, Technique System, instrumentation system
List of Abbreviations

ACSM – American College of Sports Medicine
BMI – Body Mass Index
DDR – German Democratic Republic
FISA – Fédération Internationale des Sociétés d’Aviron
ICC – Interclass Correlation Coefficient
ISAK – International Society for the Advancement of Kinanthropometry
TS – Technique System
USA – United States of America
WCS – World Class Start

All rowing related terms are defined in Appendix 1.
1.0 Introduction

1.1 Preface

Rowing is a competitive sport performed at all levels from local club level up to Olympic level. Extensive previous research has shown that particular types of physique are associated with high performance in rowing at the elite level, both on-the-water and on the land-based rowing ergometer. However, there has been limited research on University level rowers, and virtually no research on stroke by stroke measurements of rowing on-the-water.

This dissertation has two distinct themes, firstly it explores the physical attributes that are associated with improved rowing performance in Scottish rowers at University level. Secondly, it explores the potential of a newly available instrumentation system, the Technique System, in the optimisation of boat configuration; although boat design is largely standardised, there are details of boat configuration which can be adjusted in order to optimise performance.
1.2 Background to Rowing

Boats propelled by pivoted oars have existed for at least 5000 years. Racing in boats was documented in the 18th century, and developed from competition between the boatmen who provided a taxi service on the river Thames, encouraged by their customers gambling on the boatmen's performance (Redgrave, 1992). The first record of women’s racing was in 1833 on the river Thames in single sculls, with the Amateur Rowing Association being founded in 1882. In 1896 Dr Furnivall, who believed that women would benefit from taking exercise, founded a sculling club for women in London (Amateur Rowing Association, 2008). Women’s rowing was first included in the Olympics in 1976 and British women first obtained a medal at the Sydney 2000 Olympic Games. British rowing has achieved gold medals at each Olympic Games since 1984, a record not achieved in any other British sport. For the 2008 Beijing Olympics, Britain is competing in twelve (out of fourteen) different boat classifications. Eleven of these crews qualified straight from the World Championships, with the women’s pair securing a place at the recent Olympic Qualifying Regatta.

There have been many advances over the years in rowing equipment, for example, in 1872 sliding seats were introduced in England to enable the athletes to harness the power from their legs. Today it would be unsuccessful to row using purely the trunk and arms, however the introduction of sliding seats was met with some derision; Eton College initially declined to use these slides on aesthetic grounds as it was considered inelegant (Fairbairn, 1951). Another advance in rowing equipment is the materials that are used in the boat construction, with modern boat manufacturers favouring lightweight composite materials over wood. Alongside these advances in equipment there have been advances in rowing technique over the years. Rowing styles are defined by the movement of the two largest body segments, the legs and trunk, with three main styles (Kleshnev, 2007):

1 Rosenberg style – named after Allen Rosenberg, a former US national team coach. This is a traditional style which is based on Steve Fairbairn’s teachings with a strong leg activation, without significant trunk activation.
2 Adam style – Developed in the 1960s by West German coach Carl Adam. This style involved a long leg drive with simultaneous use of the legs and trunk.

3 DDR style developed by the coaches and scientists of East Germany – the most successful rowing nation in the 1970s. This style involves a large forward declination of the trunk which begins the propulsive phase, with simultaneous activation of the legs.

These styles are mainly distinguished from one another by their timing and emphasis of the use of the legs or the trunk. The rowing style that is used by the athlete correlates with the shape of the force curve if plotted, with the Rosenberg style being considered the most powerful. However, an athlete or crew is most likely to use a combination of these rowing styles that suits the morphology of the athletes involved. However, as yet there is no standardised approach to the best biomechanical technique for a given morphology (Soper & Hume, 2004).

Today’s athletes also gain the advantages of having access to sports science support, psychology, physiotherapy, dietetics; many of the top class rowers are full-time athletes through the financial support of agencies such as The National Lottery.

At the International Lucerne Regatta, the finishing time of the Mens’ Eight category has improved by 15 seconds over 2000m from the period from 1970 to 2003. Nolte (2005) attributed this to the rowers producing more energy, using this energy more efficiently or a combination of the two. This improvement in performance may be at least partly attributable to improvements in athlete support, equipment and technique.
1.3 Boats

Modern racing boats are narrow, lightweight structures. Sweep rowers use one oar each, with an equal number of rowers on each side of the boat; standard configurations are pairs (two rowers), fours, and eights. Scullers use two oars each and standard configurations are single, double and quad. Some configurations employ a cox for steering, and in others a crew member steers. A typical modern single scull is illustrated in Figure 1.1, and related rowing terms are defined in Appendix I.

![A modern racing shell](figure1_1.png)

**Figure 1.1** A modern racing shell

(Annotation: Photo reproduced with permission of Ron Wallace).
1.4 Rowing Ergometer

Another modern development is the land based rowing machine (ergometer or ergo), which simulates on-the-water rowing and is used for training and competition. It was originally designed as a training tool for occasions when the weather was too inclement for water training, but can now be used to measure forces applied by the athlete and to measure fitness under standard conditions.

The first rowing ergometer was built around 1900 and relied on linear pneumatic resistance (Cleaver, 1957), so it was not successful in simulating the movements of rowing. In the 1950s and 1960s the design had progressed to an iron wheel with a mechanical braking device, but again did not adequately simulate the movement pattern in rowing or the loading profile (World Rowing, 2006). In 1980, the first successful rowing ergometer was designed by the Dreissigacker brothers, keen oarsmen who wished to develop a useful training tool to keep them fit over the winter period (Concept 2, 2006). The Concept 2 ergometer was the result which better mimicked the rowing action and was tough enough to withstand heavy use. It has a sliding seat like that in the boat, and the force produced by the athlete is applied to a flywheel which simulates boat momentum, with air-damping which simulates boat drag.

In the latest generation of Concept 2 ergometers, the load can be adjusted by changing the damper setting from 1 – 10 on the side of the machine which alters the amount of air flow in the flywheel. With a higher damper setting, more air can escape from the fan cage, leading to greater resistance or drag. The drag factor is a measure of how quickly the flywheel decelerates, and is calculated automatically and is displayed on the monitor. The deceleration of the flywheel can be affected by local conditions such as temperature, barometric pressure, wind and dust. Therefore, to overcome this variance in local conditions the drag factor is set by adjusting the damper at the start of each session to ensure that results between different venues are comparable.

A Concept 2 model D rowing ergometer, used in this study, is illustrated in Figure 1.2. Concept 2 is the most widely used manufacturer of the rowing
ergometer and was used in all other major ergometer studies referred to in this text.

2 km time on the rowing ergometer is correlated with rowing performance on the water (Graham Smith et al. 2006; Soper & Hume, 2004; Hagerman, 1984). Indeed, a positive correlation ($r = 0.74$, $p<0.05$) exists between 2000m performance on the Concept 2 rowing ergometer and 2000m performance on the water (Ryan-Tanner et al. 1999). This supports the view that the ergometer potentially provides a representation of real rowing, and therefore a useful measurement and assessment tool.

**Figure 1.2** Concept 2 Model D rowing ergometer

(Concept 2, 2006)
1.5 Competition

2000 metres is the standard race distance in rowing both on the water and on the rowing ergometer. It has been found that stronger and heavier individuals can row faster than smaller and lighter individuals (Shephard, 1999; Bourgeois et al. 2000; Slater et al. 2005) due to greater strength, metabolic capacity and a biomechanical advantage. Therefore rowing was split into lightweight and open-class categories (in 1974 for men and in 1985 for women) to give smaller and lighter people an opportunity to compete; this decision was made by the International governing body for rowing, the Fédération Internationale des Sociétés d’Aviron (FISA) and recognises the advantageous role of size in rowing performance. For lightweight men, crew average must be 70kg or less with no-one heavier than 72.5kg. For lightweight women crew average must be 57kg or less with no-one heavier than 59kg.

Although there is a certain degree of cross-over of traits of successful performances on the water and on the ergometer (Ryan-Tanner et al. 1999), certain variables are more relevant to on-the-water rowing or to the rowing ergometer. On the rowing ergometer, there is less apparent dependence on skilful technique, with fitness, physiology and morphology playing major roles (Soper & Hume, 2004). Performance on the water is highly dependent on rowing technique, details of boat set-up (See Appendix 1 for rowing definitions), skill and compatibility of crewmates, weather conditions, power to weight ratio of the individuals, as well as the morphology of the crew plus their fitness and physiology (Graham-Smith et al. 2006)

Participants in rowing range from children to veterans and from occasional recreational rowers to Olympic competitors. Predominantly, athletes are recruited to rowing via informal processes. However, in order for GB rowing to achieve the best results at the highest level, a systematic approach to the identification of potential high performers at an early age would seem to offer advantages.
1.6 World Class Start

World Class Start (WCS) is a systematic talent identification programme that started in Great Britain in 2001, based on an Australian model. Its aim is to identify exceptional individuals, predominantly between the ages of 15 and 25, who have the physical attributes to be potential Olympic medallists. It has been previously estimated that only 1 in 10 000 people has these exceptional attributes (Shakespeare, 1980). WCS testing occurs in schools and Universities around the country and comprises measurements of height, weight and arm span as well as tests for strength and endurance. It is an American College Sports Medicine (ACSM) recommendation that young people should be encouraged towards sports that suit their body type (Bourgois, 2000). For open-class rowers GB Rowing are seeking females 178cm or taller and males 188cm or taller; for lightweight rowers they are seeking females of approximately 170cm in height who are no heavier than 64kg and males of approximately 180cm in height who are no heavier than 78kg; lightweights must be aged 18 or older. The Schwinn arm and leg bike test is used to test endurance. The Schwinn Airdyne Exercise Bike has moving arm levers as well as pedals (Schwinn, 2008) which provides a whole body workout requiring synchronisation of the arms and legs. Thus it is seen to be an appropriate test for prospective rowers without requiring the technique necessary for performing well on the rowing ergometer. The Schwinn test is also a psychological test to see how candidates attack the test which can give an indication of their mental toughness and determination. The strength testing is done on the Concept 2 Dyno® machine, where leg and arm strength are measured. A three repetition maximum strength test is performed as well as a 15 repetition bench pull test.

The majority of individuals who are identified have no previous rowing history, but once a month, WCS athletes come together from their clubs to participate in a testing weekend. Their sculling skills, technique, ability to propel the boat and physiology are all tested to assess their development. It is necessary to perform well at these testing camps in order to stay on the programme. At present there are 118 athletes participating in the WCS programme throughout Britain and since the programme started in 2001, 9 athletes have joined the British
Rowing Team on a full time basis and 172 candidates have dropped out of the programme.

To date the WCS scheme has produced athletes who have won 2 medals at the Senior World Championships, 10 athletes who have raced at the World Championships, 19 athletes who have raced at the Under-23 World Championships winning 3 gold and 6 bronze medals, 10 World Junior Rowing Championship appearances winning one silver and two bronze medals and nine gold and two bronze medals from the Coupe de la Jeunesse. Without the WCS programme it is unlikely that any of these individuals would have taken up rowing and that Great Britain would have won these medals.

Four WCS athletes were available for this study and their results are shown separately from the other participants, where relevant.

1.7 Anthropometry

The word anthropometry comes from Greek for man (anthropos) and measurement (metros) (Carter, 2002) and is the science of measurement of size and proportion of the human body and its components (Kent, 1998). Anthropometry has been widely used in studies of athletic and non-athletic groups. It is relatively quick to perform, does not require to be performed in a laboratory, the equipment needed is relatively easy to transport and hydration status does not have a major effect on the results (Slater et al. 2005); this is especially important when measuring lightweights, who may have been fasting or ‘sweat running’ to make weight.

The International Society for the Advancement of Kinanthropometry (ISAK) is the body which supplies recognised training, standards and measurement techniques. ISAK training and qualification exists at four levels, numbered from one to four. A Level 1 ISAK anthropometrist is able to complete a restricted proforma which includes 8 skinfold measures, 5 girth measures, two breadth measures plus stature and body mass. A Level 2 ISAK anthropometrist is able to measure additional girth, length and breadth dimensions which comprise a full
proforma and 39 individual measures. A Level 3 anthropometrist can additionally instruct on ISAK courses and a Level 4 criterion anthropometrist sets the standards and governs the ISAK Level 1, 2 and 3 exams. The high standard of training and attention to detail ensures comparability and consistency when measures are made by two ISAK trained anthropometrists. Another benefit of the full ISAK proforma is that is allows adiposity, muscularity and proportionality to be examined together.

An ISAK trained anthropometrist follows a very exacting set of procedures with tight guidelines on accuracy. The measure of precision in ISAK measurement is called the technical error of measurement (TEM), and is the standard deviation (SD) of repeated measurements of the same participant. If the same anthropometrist takes all of the measurements, then the TEM is called the intra-tester TEM. If two or more anthropometrists are involved in testing the same participant independently of each other then the SD of measurement is called the inter-tester TEM. If a criterion anthropometrist takes one set of measurements from a participant and these are compared to those taken by another anthropometrist, this can be used to determine the precision of the measures taken by the non-criterion anthropometrist. When comparing TEM’s from across the proforma or between participants it is useful to convert the absolute TEM into a percentage which is called the relative TEM. This is especially relevant when it is considered that skinfold measurements from a lean participant often have a low absolute TEM but from an overweight participant often have a high absolute TEM, therefore when taken as a percentage is much more useful. This can be calculated using the following formula:

\[
% \text{ TEM} = \frac{\text{TEM}}{\text{mean}} \times 100 \quad (1)
\]

(Pederson and Gore, 2002)

ISAK require that Level 2, 3 and 4 anthropometrists have a maximum TEM of 5% for skinfolds and 1% for all other measures.
1.8 Rowing Biomechanics

1.8.1 Methods of Assessment

Biomechanical analysis of on-the-water rowing dates back approximately 150 years (McBride, 2005), with the aim to investigate the way in which the athletes convert their physiological capacity into moving the boat, and to improve technique. Over the years advances in terms of the sophistication of the devices used to measure these biomechanical parameters have been made. In the 1950s, contact methods such as strain gauges were used to measure propulsive forces, however an umbilical cable was needed to relay the data to a following motor boat, but by the 1970s advances had been made and this data was able to be sent directly to a land based recorder via a FM transmitter (McBride, 2005). Non-contact methods such as video or photography were often the only way of capturing data during competition, however such methods led to time consuming data processing (Kleshnev, 2005). The requirements of a modern day instrumentation system are that it does not interfere with the rower or the oar, that it does not add undue weight to the boat, is transportable, impermeable to splashing or if the rower were to capsize and that the information is immediately available to the coach and athlete so that there is no lag time. The method used in this project satisfied all of these requirements.

1.8.2 Levers

In rowing the oar is, in a sense, a lever. The force applied to the handle by the athlete also generates forces on the fulcrum (the pin) and on the load (the spoon in the water), generating boat propulsion. Levers have a mechanical advantage which is the ratio between the applied force and the force experienced by the load (Baudouin & Hawkins, 2002). In rowing this ratio is the ratio of the inboard length of the oar (x) to its outboard length (y). Therefore, the mechanical advantage = x/y. A taller athlete would naturally pull the handle through a longer distance. For a fixed inboard length, this would translate into a larger angle A, but because Cos (A) drops rapidly away from its peak value of 1.0 at 0°, there would be a loss of efficiency. Thus taller athletes employ a
different set-up where the inboard length is increased by moving the pin outwards; this increases length x and for a given length of oar decreases the outboard length y. The increase in length x accompanied by a decrease in length y gives a substantial increase in the mechanical advantage $x/y$, and a proportionately greater propulsive force on the spoon.

1.8.3 Biomechanics of Rowing Movement

The oar is the link between the force generated by the rower and the propulsion of the boat, with the force on the handle being generated by the sequential muscular activation of the rower. This force is transferred via the oarlock to propel the boat. McBride (2005) suggests that the resultant force on the blade as it is pulled through the water is at right angles to the blade surface. As the blade moves through the water in an arc, the orientation of this force vector with respect to the direction of the boat will change.

\[A = \text{angle of attack}\]
\[FT = \text{transverse force}\]
\[FR = \text{resultant blade force}\]
\[FP = \text{propulsive force}\]

Figure 1.3  Blade Forces (adapted from McBride (2005))

Only a portion of the blade force vector will act parallel to the long axis of the boat and contribute to propulsion. The other portion acts perpendicular to boat
motion and is not involved in propulsion but is counterbalanced by oars on opposite sides in sculling and creates a turning force in sweep rowing; this turning force is counterbalanced by strokeside and bowside rowers adopting a slightly different force versus angle profile (Nolte, 1991). Vector resolution allows these two components to be calculated.

\[ FP = FR \cos A \quad (2) \]
\[ FT = FR \sin A \quad (3) \]

Thus the orthogonal position \( A=0^0 \) is the most effective since \( \cos (0^0) = 1 \); for the larger angles, \( \cos A \) reduces from its maximum value of 1 and the propulsive force \( FP \) drops accordingly. The force \( FR \) produced by the athlete is not constant but will be a function of muscle activation, joint angles and leverage. Changes to stretcher position will change the relationship between \( FR \) and the orthogonal position and therefore change peak acceleration. The total acceleration of the boat is the combination of the force produced by the athlete on the handle and the transfer of that force to boat propulsion. A change in stretcher position changes the relationship between the position of maximum force applied and the position where the oar is most efficient, and therefore will change the measured peak acceleration.

The most effective use of the rower’s strength is before the orthogonal (Nolte, 1991). The figure below shows the ideal force curve (in that the peak force is applied just before the orthogonal) in relation to the catch, the orthogonal and the finish of the stroke.

**Figure 1.4**  Force Profile (adapted from Nolte (1991))
1.9 Overview of the Technique System

Traditionally, the only objective on-the-water performance measure is time over a standard distance. This measure is supplemented by the skill of the coach, who trains and develops the technique of the athletes, judging technique by eye. Certain aspects of boat set up are guided by similar, largely unquantified, judgments and the optimum boat set up is often found by exhaustive trial and error which can affect the athletes’ performance over the course of the season. The Technique System (TS) is a newly developed instrumentation system developed to provide the athlete and coach with quantitative information about the crew’s rowing technique. It is comprised of an on board computer, blade sensors, boat dynamics sensor and off-line PC analysis software, and measures in real time the detail of each rowing stroke plus associated boat movement (Precision Sport, 2006).

1.10 Previous Research in Rowing Performance

Most previous research investigating the ideal morphology of rowers in relation to performance both on the rowing ergometer and on the water has been conducted in elite level senior rowers (Kerr et al. 2007; Slater et al. 2005; DeRose et al. 1989 and Hebbelinck et al. 1980), but some studies have focused on elite junior, University and club level rowers. This previous research demonstrates that there are clear morphological trends in successful elite rowers, but there is insufficient existing research on University level rowers to confirm that these trends also exist at this level in rowing. Particularly in on-the-water performance, previous instrumentation systems have been rudimentary, so only limited research has been conducted into the details of rowing technique. Various authors use a range of techniques for data analysis of body morphology, but widely used techniques are phantom z scores and somatotyping (see Sections 2.4 and 2.5 for specific details of these techniques).
1.10.1 Previous Research based on the Rowing Ergometer

Graham-Smith et al. (2006) examined the relationship between physical, anthropometric and technical factors on 2000m and 5000m rowing ergometer performance. 18 male University and Club level rowers with 2 or more years rowing experience were tested. Anthropometric variables included stature and body mass. Peak power was measured on the rowing ergometer by performing a 5 stroke maximal test, strength was measured on the Concept 2 Dyno® and flexibility was measured by a sit and reach test. Details of technique were measured from video camera footage; stroke length, drive time, recovery time and ratio were all measured. It was found that stature alone accounted for 60% of variance in 2000m score (p<0.01) and 50% in the 5000m test. Body mass of the athlete was found to account for 29% of the variance (p<0.01). Graham-Smith et al. also found that stroke length was a highly significant factor in 2000m performance and suggested that a longer stroke will inject more energy per stroke for the same applied force (r= 0.45, p<0.01).

Yoshiga and Higuchi (2003) evaluated male and female rowing performance with regard to the athletes’ size. They measured 71 females and 120 males all aged between 18 and 24 years of age. Yoshiga and Higuchi observed that 2km time improved with body size. The 2000m time was negatively correlated to stature (r=-0.81), body mass (r=-0.85), fat-free mass (r=-0.91) and ŔO₂ max (r=-0.90) all at the p<0.01 level. A high fat free mass resulted in a high level of rowing performance.

Jürimäe and Jürimäe (2002) did a comparison of anthropometric parameters in 9 lightweight and 11 open-class national level Estonian rowers. Their performance was measured by a 2000m all-out test on the ergometer. The anthropometric variables studied were skinfolds, muscle mass, skeletal mass and the cross sectional area of the thigh. They concluded that the anthropometric and metabolic characteristics differ between lightweights and open-class rowers with stature, body mass, Body Mass Index, lean body mass, thigh cross-sectional area, skeletal mass and ŔO₂ max (l.min⁻¹) all being lower in
lightweights which can mainly be explained by the weight restriction of the lightweight category.

1.10.2 Previous Research of On-The-Water Performance

Hebbelinck et al. (1980) studied 51 female rowers competing at the 1976 Montreal Olympic Games. This represented 23% of the female competitors (who were the first females to ever compete in rowing at an Olympic Games). Hebbelinck et al. compared the anthropometric characteristics of these rowers to a group of University students. It was found that the rowers were taller (8.6cm), heavier (9.9kg), had larger muscle mass (5.45kg) and were larger in every measurement with the exception of all 6 skinfold measurements. The rowers were found to have mean Heath-Carter somatotype (see section 2.5) of 3.1-3.9-2.8 and the students a mean of 4.0-3.5-2.9 with a smaller scattering of somatotypes amongst the rowers. When scaled to the phantom z for proportionality (see section 2.4), the rowers were found to be similar to the reference group, except for having greater tibiale height (rowers had a z score of -0.85 versus -1.18), a wider transverse chest (rowers had a z score of -1.2 versus -1.61), larger flexed arm girth (rowers had a z score of -0.35 versus -0.84) and forearm girths (rowers had a z score of -0.14 versus -0.64) and were smaller in all 6 of the skinfolds. This greater tibiale height is thought to account for the shorter proportional sitting height found amongst the rowers. This was a landmark study into the anthropometric characteristics of female Olympic rowers.

Kerr et al. (2007) studied the physical and proportional characteristics of lightweight and open-class rowers competing at the Sydney Olympics in 2000. 190 male (140 open-class and 50 lightweight) and 83 female (69 open-class and 14 lightweight) athletes were measured for the full ISAK proforma in the 15 days prior to competing in the Olympic Games. Kerr et al. (2007) also measured a control group of healthy young adults (42 males and 71 females) who were all non-rowers. They found body mass, stature and sitting height to be significantly different between all 3 groups (lightweights, open-class and the comparison group). Even after scaling for stature, open-class rowers were
found to be proportionally heavier than the lightweight rowers with greater proportional chest, waist and thigh dimensions (p<0.01). Both lightweight and open-class rowers were found to have a significantly smaller hip girth when compared with the non-rowers. Female open-class athletes were found to be 6cm taller and 12.1kg heavier than the female competitors at the Montreal Games. The increase in height in this time due to secular trend is ~3.2cm, which shows that the height increase in rowers is nearly double that of secular trend (Norton & Olds, 2001). When looking at the seven highest placed competitors it was found that these male open-class athletes were significantly taller (2cm), heavier (3.4kg) and had a greater sitting height (1.6cm) (p<0.01) than the rest of their competitors. These highly placed male open-class athletes were also found to be more muscular with greater flexed arm girths (36.8cm versus 35.9cm) and forearm girths (31.2cm versus 30.5cm). Female open-class rowers who were placed highly were found to have a lower sum of skinfold thickness than their lower ranked opposition (82.1cm versus 99.8cm). The highly placed male lightweights were found to have a significantly (p<0.01) longer proportional thigh length with a z score of 1.155 against 0.67.

As DeRose et al. (1989) found that power to weight ratio is especially important in rowing because “size has an advantage when the extra weight does not add more to the resistance of the shell than it contributes to the propulsive forces applied to the water”. Although rowing is not a weight bearing activity, with an increase in weight the boat sits lower in the water with a greater surface area in contact with the water, which in turn means that there will be more drag opposing the motion of the boat (Baudouin & Hawkins, 2002). DeRose et al. (1989) studied lightweight rowers competing at the 10th Pan American Games. They obtained anthropometric data on 20 male and 13 female athletes competing at the games, including most medal winners. Full ISAK proformas were obtained from all athletes and it was found that male lightweight rowers were similar to the student control sample, except in terms of their short sitting height (92.5cm versus 94.1cm), lower readings in all skinfold thicknesses and large transverse chest breadth (29.1cm versus 28.4cm). The female lightweight rowers were found to be clustered in two morphological groups and were quite different to the reference group. The rationale given was that at that time
women’s rowing was still developing, thus the taller group were meeting the weight restriction by having low skinfolds and being very linear, and the second group were maximising their weight by being more muscular as they were naturally shorter in stature.

Slater et al. (2005) studied 65 male and 45 female lightweight rowers who were competing in single sculls in the 2003 Australian Rowing Championships. Slater et al. took full ISAK anthropometric profiles from these athletes and found performance to be significantly positively correlated (p<0.01) with muscle mass and absolute body mass of an athlete (the latter only in the case of heavyweight rowers). Additionally, they found that low skinfolds, greater total body mass and greater total muscle mass were all associated with faster heat times. These characteristics were also found to be true when looking for anthropometrical differences between those who made the ‘A’ final and those who did not. Both the oarsmen and oarswomen were found to have proportionally low skinfolds and long thigh lengths when scaled to the phantom z, in the study by Slater et al. (2005).

At the 1997 World Junior Rowing Championships in Hazewinkel, Belgium, a team of anthropometrists led by Jan Bourgois (Bourgois et al. 1997) gathered data from 603 male and female rowers. This study vastly exceeded the size of most other studies of this kind and is held in high regard in the world of anthropometry due to the size and rigour of the study. 89.3% of competitors (n=603) were measured and they were found to be 7% taller and 25% heavier than age matched non-rowers (p<0.01). 383 male junior rowers were measured; this included 83% of the medallists and 89% of the male competitors. Their age was 17.8±0.7 years and they trained between 10 and 15 hours a week. Their morphology was compared with a reference group of age matched Belgian boys. The rowers were found to be: 17.5kg heavier, 12cm taller and with greater length, breadth and girth dimensions than the age matched control group (p<0.01). In fact, the most successful athletes had distinctive stature, skeletal breadths and muscular development. Interestingly, this study was extended to the investigation of the differences between finalists and non-finalists. Those who reached the finals were found to be taller, heavier
and have greater length, breadth (except biiliocristal) and girth dimensions than
the non-finalists. These finalists were also found to have a lower sitting height
and longer leg length relative to their stature. 90% of female competitors
(n=220) aged 17.5±0.8 were also measured for 27 body dimensions. They
were found to be taller (10.8cm), heavier (13.7kg), have smaller readings in all
6 skinfold measurements and greater length (leg length was greater by 7.1cm),
breadth (biacromial breadth was greater by 2.4cm) and girth measurements
(thigh girth was greater by 4.7cm) when compared with age matched Belgian
schoolgirls (p<0.01).

Jürimäe and Mäestu (1999) investigated inter-relations between anthropometric
variables and 2000m performance on both the rowing ergometer and in single
sculls. 10 experienced male rowers completed a VO$_2$ max test, a 2000m
ergometer test and a 2000m timed race in a single scull. They found that
muscle mass was negatively correlated (r=-0.64, p<0.05) with performance time
in the single scull. When looking for relationships between 2000m ergometer
time and morphology, the following were found to be significantly correlated:
stature (r=-0.77), body mass (r=-0.91), body mass index(r=-0.63), lean body
mass(r=-0.91), cross-sectional area of the thigh(r=-0.66), muscle mass (r=-
0.85) and skeletal mass(r=-0.88) at the p<0.05 level. A significant correlation
coefficient of r=0.72, p<0.05 was observed between the 2000m ergometer and
single scull times.

1.10.3 Analysis of previous research

Overall, the findings of these studies since the 1970s largely agree on the
physical attributes associated with an increased performance in rowing. The
results for females differ somewhat over this time as female rowing is relatively
recent and has been emerging during this time, unlike male rowing which is
more established, with greater numbers of men competing.

The energy input per stroke contributing to boat propulsion is force multiplied by
distance so it is to be expected that taller athletes and those with longer limbs
will have an advantage (Graham-Smith et al. 2006). When comparing the
physique of medallists to non-medallists, it has indeed been found that medallists have longer extremities, are taller in stature, have greater girths and breadths (except pelvis breadth) than non-medallists (Kerr et al. 2007; Slater et al. 2005; Bourgois et al. 2000). When compared with scullers, sweep rowers were found to be heavier, taller, have greater skinfold measurements, greater breadth measurements (except for femur), greater length measurements and greater girth measurements (except for calf girth) (Bourgois et al. 2000; Bourgois et al. 2001). Sweep boats have less oars and generally have more people in them (four or eight) and are often coxed therefore feel much heavier to row in as the cox is dead weight and the boat decelerates much more quickly; therefore more force is needed to accelerate the boat on every stroke. This explains why sweep oared and coxed crews are more successful when rowed by more robust athletes.

Overall, successful rowers are found to be taller, heavier, have an increased muscle mass, and a lower body fat than non-rowers, by a significant margin. The increase in size of athletes in this time has far outstripped that of secular trend. When scaled to the phantom z rowers tend to be found to have long thigh bones and a short sitting height, although there has been some variation of findings with regard to sitting height.

1.10.4 Previous Research in Boat Set Up

Barrett & Manning (2004) investigated the relationship between rigging set up, anthropometry and performance. 15 elite single scullers morphology and boat rigging were measured and their 2km race times were taken from the Australian national selection trials. Barrett & Manning noted that the configuration of the boat had received little consideration in the literature up to that time. They found body mass ($r=-0.87$) and height ($r=-0.86$) to be highly negatively correlated with race time ($p<0.001$). Rigging set up was found to differ between the best rowers and the rest, but this was attributed to the fact that the faster rowers were bigger and stronger therefore their rigging was scaled up appropriately for their size. This led to the conclusion that some aspects of rigging set up should not be considered primary determinants of performance.
Although the r value was not given in the text, Barrett & Manning concluded in their discussion that foot stretcher-seat distance will influence catch and finish angles and the contribution of propulsive and turning forces, thereby influencing boat speed.

A similarity between altering the stretcher position in a sculling boat and altering the seat height of a bicycle is apparent. As in rowing, cycling has a power phase where the hip, knee and ankle joints all extend simultaneously for the pushing action and a recovery phase whereby these joints are flexed in order to return to the starting position of the power phase (So et al. 2005). Additionally, Barfield et al. (2003) have found there to be similarities in cardiovascular responses in rowing and cycling ergometry. Both are cyclic movements although obviously cycling uses one leg at a time in the power phase, and rowing both. In cycling it has been shown that the effectiveness of force production is altered by the joint angles, resulting muscle lengths and muscle moment arms, with these variables being altered by changes in cadence, seat height and orientation of the body (So et al. 2005). Gonzalez and Hull (1989) found that as the morphological size of the athlete increases so to does the optimal seat height in cycling. Price and Donne (1997) found that as seat height is increased, there is an increase in the extension of the knee and ankle, and the ankle plantar flexion is increased near the bottom of the pedal revolution to stop the knee from over extending. However, once seat height is greater than 100% of trocanterion height, there is a need to tilt the pelvis to provide extra leg length therefore this side to side movement could explain the greater cardiorespiratory cost and decrease in performance with a seat height of more than 100% of trocanterion height.

It is therefore anticipated that similar changes in geometry will be of importance to rowing performance. The TS is a very recent development (2006) and there is no literature on the use of this specific system published in peer reviewed journals. There are some short articles in rowing-related magazines and these suggest that the TS does hold some promise in the optimisation of rowing technique and boat set-up. In 2004, Soper and Hume concluded in their study into ideal rowing technique for performance that future research should be focused on the area of foot stretcher orientation in rowing. Section 1.8.3
demonstrates that it is likely that propulsive forces applied by the oar depend on the physical position of the rower relative to the oar orthogonal position, and this depends on stretcher position. The TS affords an opportunity to measure changes in boat movement, on a stroke by stroke basis, with altered foot stretcher position.

1.11 Aims and Objectives of the Current Investigation

The fundamental hypothesis to be tested in this study is that body types associated with high performance will be similar between elite rowers (where these factors are well understood) and Scottish University level rowers. Two approaches were employed (1) establishing the relationship between 2km ergometer time and body morphology, and (2) establishing the relationship between boat peak acceleration and body type.

Experiment 1

The first aim of this project is to investigate the determinants of successful rowing performance in terms of body morphology in University level athletes. The specific aim is to associate performance on the rowing ergometer in an all-out 2000m test with proportionality, muscularity, adiposity and size. A related aim is to develop a model to predict 2000m rowing performance on the rowing ergometer on the basis of body morphology.

Experiment 2

The second aim of this project is to investigate the application of the Technique System, by using it to measure the peak acceleration that an athlete in a single scull can achieve with different stretcher configurations and to relate this to stretch stature and body mass.
2.0 Methods and Materials – Experiment 1

2.1 Participants

Participants were recruited from the major clubs competing at the Scottish University Indoor Rowing Championships in 2007 and in 2008 by advertising on the Scottish Amateur Rowing Association’s website prior to the Championships and by sending out information via e-mail to all University Club Captains in Scotland. 50 male (27 open-class, 20 lightweight and 3 WCS) and 22 female (18 open-class, 3 lightweight and 1 WCS) rowers were measured for the full 39 ISAK anthropometric dimensions within 14 days of completing a 2000m all-out time trial on the rowing ergometer. This represents 49.6% of total competitors at the Championships.

2.2 Study Design

All participants were given an information sheet prior to volunteering to take part in this study (see Appendix II). Informed consent was obtained before any measurements were taken. All participants also completed a Physical Activity Readiness Questionnaire (see Appendix III) prior to taking part in this study. Ethical approval had been granted by the Robert Gordon University Ethics Committee for these measurements to be taken.

All time trials were completed on Concept 2 Model D rowing ergometers during the Scottish Indoor Rowing Championships 2007 and 2008. The ergometers were calibrated and used in line with the manufacturer’s instructions, and were all taped down securely to the gymnasium floor to prevent them moving, which can adversely affect performance. Participants’ 2000m times were obtained from the Concept 2 website in the week following the Championships.
2.3 Anthropometric Data Collection

All anthropometric measurements were taken by three Level 2 ISAK trained anthropometrists. It takes approximately one hour to measure and process each participant therefore during most anthropometric studies there are teams of anthropometrists working together, as was the case in this study. Of the total 72 participants, the author completed 54 of the full ISAK proformas. The remaining 18 participants were measured by two fellow Level 2 ISAK anthropometrists.

The 39 measurements included: 8 skinfold measurements, 13 girth measurements, 10 length measurements, 6 breadth measurements plus body mass and stretch stature. (See appendix IV for anatomical definitions).

Table 2.1 Measurement Sites

<table>
<thead>
<tr>
<th>Skinfolds</th>
<th>Girths</th>
<th>Lengths</th>
<th>Breadths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricep</td>
<td>Head</td>
<td>Acromiale-radiale</td>
<td>Biacromial</td>
</tr>
<tr>
<td>Subscapular</td>
<td>Neck</td>
<td>Radiale-stylios</td>
<td>Biiliocristal</td>
</tr>
<tr>
<td>Bicep</td>
<td>Arm Relaxed</td>
<td>Midstylios-dactylios</td>
<td>Transverse Chest</td>
</tr>
<tr>
<td>Iliac Crest</td>
<td>Arm Flexed &amp; Tensed</td>
<td>Iliospinale</td>
<td>A-P Chest Depth</td>
</tr>
<tr>
<td>Supraspinale</td>
<td>Forearm</td>
<td>Trocanterion</td>
<td>Biepicondylar humerus</td>
</tr>
<tr>
<td>Abdominal</td>
<td>Wrist</td>
<td>Trocanterion-Tibial</td>
<td>Biepicondylar femur</td>
</tr>
<tr>
<td>Front Thigh</td>
<td>Chest</td>
<td>Laterale</td>
<td></td>
</tr>
<tr>
<td>Medial Calf</td>
<td>Waist</td>
<td>Tibiale Laterale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gluteal</td>
<td>Tibiale mediale-sphyriion tibiale</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thigh</td>
<td>Foot length</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mid-thigh</td>
<td>Sitting Height</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calf</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ankle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
From these measurements corrected arm girth, corrected calf girth, corrected forearm girth, corrected waist girth, muscle mass, fat free mass and arm spread were calculated (see Appendix V for details of corrections and for equations). Standard ISAK procedure was followed at all times (ISAK, 2006).

Body mass was measured to the nearest 0.1kg using a set of Seca scales (Seca Ltd, Birmingham, UK), stature and sitting height were measured to the nearest 0.1cm with a Leicester height measure (Seca Ltd, Birmingham, UK). All skinfolds were measured with a set of Harpenden 0120 skinfold callipers (Harpenden Ltd, British Indicators, UK) and were taken to the nearest millimetre and girths were measured using a Rosscraft flexible steel measuring tape to the nearest millimetre. Finally, skeletal lengths and breadths were measured using a Rosscraft segmometer or a set of large sliding calipers (Rosscraft Campbell Caliper 20, Surrey, Canada) with the latter for measuring foot length only – all of these measures were taken to the nearest 0.1cm.

All three anthropometrists were trained by the same criterion anthropometrist and underwent additional practice prior to the Indoor Rowing Championships. In order to calculate the inter-tester TEM all three Level 2 anthropometrists and a Level 4 criterion anthropometrist measured one of the participants. Inter-tester TEM was below the ISAK Level 2 limit of less than 5% for the skinfolds and 1% for all of the other measures.

### 2.4 Z Scores

Relative size characteristics were calculated by using Phantom Z-scores (Ross & Wilson, 1974) which are useful when comparing two or more individuals or two or more groups. Z scores are based on the concept of a theoretical reference human – the Phantom - who is a unisex, bilaterally symmetrical model (Ross & Wilson, 1974). The Phantom means and standard deviations were derived from an amalgamation of male and female data from various studies including Garret and Kennedy, Behnke, Wilmore and Behnke and Clauser et al. (Ross & Wilson, 1974). Z scores are of most value when comparing proportional differences between one group of participants and another, rather than when looking at the
characteristics of one individual or group. This is due to the fact that z scores do not represent deviations from an actual population norm (Olds et al. 2002), as the data underpinning the Phantom are diverse and will not necessarily be an appropriate reference population; this is compounded by the fact that some of the data in the literature used were ambiguous and not necessarily normally distributed. Nevertheless, when z scores are used in context to compare the proportionality differences between groups – in this case Open-class, lightweight and WCS rowers, they can show up differences between the groups.

The z score is defined as:

$$z = \frac{1}{s} \left[ \frac{l (170.18)^d - p}{h} \right]$$

Where

- $z$ = a proportionality value of z-score
- $l$ = the variable under discussion
- $s$ = the phantom SD for the given variable
- 170.18 = the phantom height constant
- $h$ = the subject’s height
- $d$ = a dimensional exponent which is 1 for all heights, lengths, breadths, girths and skinfold thicknesses; 2 for all area values and 3 for all weights and volumes
- $p$ = the phantom mean value for the variable

(Ross & Wilson, 1974)

### 2.5 Somatotype

One method of physique classification is known as somatotyping. Interest in individual body types can be traced back in history to the ancient Greeks (Carter, 2002) and the Heath-Carter classification system is used here to calculate the somatotype for all participants (Carter, 1980). Somatotyping describes an individual in terms of body shape and composition with regard to endomorphy (relative fatness), mesomorphy (relative muscularity) and ectomorphy (relative linearity). A three number rating is given to describe the individual’s physical characteristics as an integrated entity. Somatotyping has been used in this project firstly to describe the participants, but also to look for a relationship between the athletes’ somatotype and their 2km ergometer performance. See Appendix VI for details of somatotype calculations.
2.6 Statistical Analysis

Statistical analyses were performed in Excel (2003) and the Statistical Package for Social Sciences (SPSS version 15.0). Data were checked for normality and log transformed where necessary. Independent samples t-tests were performed to examine differences between the open-class and lightweight groups. Pearson correlations between the athletes’ 2km time and their physical characteristics were completed to find the best predictor variables. One way ANOVAs plus pairwise comparisons of means were used to determine significant differences in z score measurements between the groups of rowers. Finally, a stepwise regression analysis was performed to obtain a prediction model for University rowers 2km time based on body morphology. Significance was set appropriately with a Bonferroni correction to describe the relationships between the variables, 0.05 was divided by 39 (the number of pairwise comparisons). Therefore significance was set at p<0.00128.
3.0 Results – Experiment 1

3.1 Basic Measurements

Basic descriptive measurements of the participants are given in Table 3.1. The values given are means ± SD for each group. An independent samples t-test was performed to identify the statistically significant differences between the open-class and lightweight groups for both the males and the females.

Table 3.1 Physical Characteristics of Participants

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open-class (n=30)</td>
<td>Lightweight (n=20)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>23.8 ± 6.2</td>
<td>20.1 ± 1.3</td>
</tr>
<tr>
<td>Σ 8 skinfolds (mm)</td>
<td>84.3 ± 26.6</td>
<td>64.6 ± 17.5</td>
</tr>
<tr>
<td>Muscle mass (kg)^</td>
<td>50.5 ± 6.3*</td>
<td>41.4 ± 3.4</td>
</tr>
<tr>
<td>2km time (s)</td>
<td>407.6 ± 17.5*</td>
<td>433.2 ± 16.3</td>
</tr>
<tr>
<td>Rowing experience (years)</td>
<td>3.5 ± 3.0</td>
<td>2.5 ± 2.0</td>
</tr>
<tr>
<td>Training sessions per week</td>
<td>6.8 ± 3.3</td>
<td>6.0 ± 1.7</td>
</tr>
</tbody>
</table>

^ This was calculated by the Drinkwater & Ross (1986) equation
* denotes a statistically significant difference between open class and lightweight rowers at p<0.00128 as computed by an independent samples t-test.
3.2 A comparison of the anthropometric characteristics between Open-class, Lightweight and WCS rowers

The following graphs show the mean raw data collected from the 72 participants. In section 3.2 the participants are split into 3 groups, open-class, lightweight and World Class Start. Due to the small sample size of the World Class Start athletes (n=4), they have been put back into their respective open-class or lightweight groups for the Pearson’s correlations and for the stepwise regression.

3.2.1 Male Skeletal Lengths

![Male Skeletal Lengths Chart]

*Error bars show +1 SD*
Figure 3.2.1 shows the differences in measures of skeletal lengths between male open-class, lightweight and WCS rowers.
Figure 3.2.2 shows the differences in skeletal lengths between female open-class, lightweight and WCS rowers.
3.2.3 Male Skeletal Breadths

Figure 3.2.3 shows the differences in skeletal breadths between male open-class, lightweight and WCS rowers.
3.2.4  Female Skeletal Breadths

Figure 3.2.4 shows the differences in skeletal breadths between female open-class, lightweight and WCS rowers.

Error bars show +1 SD
Figure 3.2.5 shows the girth measurements for the male open-class, lightweight and WCS rowers.
3.2.6 Female Girths

Figure 3.2.6 shows the differences in girth measurements between the female open-class, lightweight and WCS rowers.
Figure 3.2.7 shows the differences in skinfold measurements between the male open-class, lightweight and WCS rowers.
3.2.8 Female Skinfolds

Figure 3.2.8 shows the differences in skinfold measurements between the female open-class, lightweight and WCS rowers.

3.3 Independent Samples T Test

An independent samples t test was performed between the open-class and lightweight groups. If Levene’s test showed that \( p < 0.00128 \) (corrected for Bonferroni), variance was assumed. The following tables show those characteristics which were significantly different between the open-class and lightweight groups.
**Table 3.2**

Physical characteristics that were found to be significantly different between the Open-class and lightweight males, as computed by an independent samples t-test. P values are given in parenthesis.

<table>
<thead>
<tr>
<th>Girths</th>
<th>Skeletal Lengths</th>
<th>Breadths</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm Relaxed</td>
<td>Waist (.0000062)</td>
<td>Stature (.000093)</td>
<td>Transverse Chest</td>
</tr>
<tr>
<td>Arm Flexed</td>
<td>Gluteal (.00030)</td>
<td>Sitting Height (.00066)</td>
<td>A-P Chest Depth</td>
</tr>
<tr>
<td>Forearm (.00067)</td>
<td>Thigh (.00000045)</td>
<td>Radiale-Styliion (.000078)</td>
<td>Femur (.0012)</td>
</tr>
<tr>
<td>Chest (.000002)</td>
<td>Mid Thigh (.000003)</td>
<td>Iliospinale (.00022)</td>
<td>Arm Spread (.000095)</td>
</tr>
<tr>
<td>Corrected Calf</td>
<td>Calf (.00021)</td>
<td>Tibiale Laterale (.00056)</td>
<td>Muscle Mass (.000003)</td>
</tr>
<tr>
<td>(.00054)</td>
<td></td>
<td></td>
<td>Subscapular sf (.00013)</td>
</tr>
<tr>
<td>Corrected Thigh</td>
<td>(.0000015)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.3**

Physical characteristics that were found to be significantly different between the Open-class and lightweight females, as computed by an independent samples t-test. P values are given in parenthesis.

<table>
<thead>
<tr>
<th>Breadths</th>
<th>Skinfolds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Chest</td>
<td>Subscapular (.00033)</td>
</tr>
<tr>
<td>(.00013)</td>
<td>Biceps (.000071)</td>
</tr>
<tr>
<td></td>
<td>Front Thigh (.0013)</td>
</tr>
<tr>
<td></td>
<td>Medial Calf (.0013)</td>
</tr>
<tr>
<td></td>
<td>Abdominal (.00097)</td>
</tr>
<tr>
<td></td>
<td>Sum 8 Skinfolds (.000090)</td>
</tr>
</tbody>
</table>

43
3.4 Somatoplots

The athletes’ somatotypes were calculated (see Appendix VI) and plotted using Microsoft Excel.

3.4.1 Males

Somotoplot showing the somatotypes of each individual male participant.

- Open Class Males (n=27)
- Lightweight Males (n=20)
- World Class Start Athletes (Open Class) (n=3)
### 3.4.2 Top Ranked and Lowest Ranked Males

Somatoplot showing the somatotypes of the top five ranked and lowest five ranked open class and lightweight male participants, ranked by 2km time performed at the Scottish Indoor Rowing Championships.

![Somatoplot](image)

- **Top 5 Ranked Open-class Males**
- **Lowest 5 Ranked Open-class Males**
- **Top 5 Ranked Lightweight Males**
- **Lowest 5 Ranked Lightweight Males**


3.4.3 Females

Somatoplot showing the somatotypes of each individual female participant.
3.4.4 Top Ranked and Lowest Ranked Females

Below is a somatoplot of showing the somatotypes of the top three ranked and lowest three ranked open class female participant, ranked by 2km time performed at the Scottish Indoor Rowing Championships. Lightweight female rowers are not described in this somatoplot owing to the small sample size of lightweight female rowers.

△ Top 3 Ranked Open-class Females

□ Lowest 3 Ranked Open-class Females

3.5 Z Scores

The diagrams below show the athletes z scores which were computed via the ISAK spreadsheet. Error bars show +1 SD.
3.5.1 Male Skinfolds

The z score diagram below shows the mean z scores for skinfolds for male lightweight, open class and WCS rowers at the eight ISAK skinfold sites.

- Open Class Males (n=27)
- Lightweight Males (n=20)
- World Class Start Athletes (Open Class) (n=3)

Error bars show +1 SD
3.5.2 Female Skinfolds

The z score diagram below shows the mean z scores for skinfolds for female lightweight, open class and WCS rowers at the eight ISAK skinfold sites.

Error bars show +1 SD
3.5.3 Male Girth Measurements

The z score diagram below shows the mean z scores for girth measurements for male lightweight, open class and WCS rowers.

Error bars show +1 SD
3.5.4 Female Girth Measurements

The z score diagram below shows the mean z scores for girth measurements for female lightweight, open class and WCS rowers.

- Open Class Females (n=18)
- Lightweight Females (n=3)
- World Class Start Athlete (Lightweight) (n=1)

Error bars show +1 SD
3.5.5 Male Skeletal Dimensions

The z score diagram below shows the mean z scores for skeletal measurements for male lightweight, open class and WCS rowers.

Error bars show +1 SD
3.5.6 Female Skeletal Dimensions

The z score diagram below shows the mean z scores for skeletal dimensions for female lightweight, open class and WCS rowers.
3.5.7 Analysis of z score results

One-way ANOVAs followed by pairwise comparisons of means were completed to determine the significant differences in z scores between the five groups of rowers over all the different measurements and are summarised in the tables which follow. The female WCS athlete was incorporated into the lightweight group for this analysis. Z scores are based on unisex phantom reference values therefore they provide a means to investigate proportionality differences between genders as well as within genders. Significance was set at p<0.05 and the detail is given as to which group mean is higher (H) or lower (L) than the group it is being compared to.
### Table 3.4 Analysis of skinfold z scores

<table>
<thead>
<tr>
<th>Skinfold Site</th>
<th>Male Open-class (MOC)</th>
<th>Male Lightweight (ML)</th>
<th>Male WCS (MWCS)</th>
<th>Female Open-class (FOC)</th>
<th>Female Lightweight (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triceps</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>MOC (H)***</td>
<td>ML (H) ***</td>
<td>FOC (L) **</td>
</tr>
<tr>
<td>Subscapular</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>MOC (H)***</td>
<td>ML (H) ***</td>
<td>FOC (L) **</td>
</tr>
<tr>
<td>Biceps</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>MOC (H)***</td>
<td>ML (H) ***</td>
<td>FOC (L) **</td>
</tr>
<tr>
<td>Iliac Crest</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>MOC (H)***</td>
<td>ML (H) ***</td>
<td>FOC (L) **</td>
</tr>
<tr>
<td>Supraspinale</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>MOC (H)***</td>
<td>ML (H) ***</td>
<td>FOC (L) *</td>
</tr>
<tr>
<td>Abdominal</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>MOC (H)***</td>
<td>ML (H) ***</td>
<td>FOC (L) *</td>
</tr>
<tr>
<td>Front Thigh</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>MOC (H)***</td>
<td>ML (H) ***</td>
<td>FOC (L) *</td>
</tr>
<tr>
<td>Medial Calf</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>MOC (H)***</td>
<td>ML (H) ***</td>
<td>FOC (L) **</td>
</tr>
</tbody>
</table>

* p<0.05, ** p<0.01, *** p<0.001

MOC= Male open-class, ML= Male lightweight, MWCS= Male World Class Start
FOC= Female open-class, FL= Female open-class
Table 3.5  Analysis of girth measurement z scores

<table>
<thead>
<tr>
<th>Morphological Characteristic (Girths)</th>
<th>Male Open-class (MOC)</th>
<th>Male Lightweight (ML)</th>
<th>Male WCS (MWCS)</th>
<th>Female Open-class (FOC)</th>
<th>Female Lightweight (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>FOC (L) *</td>
<td>MOC (H) ***</td>
<td>MOC (H) ***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ML (H) ***</td>
<td>MWCS (H)*</td>
</tr>
<tr>
<td>Neck</td>
<td>FOC (H) **</td>
<td>FOC (H) *</td>
<td></td>
<td>MOC (L) **</td>
<td>MOC (L) *</td>
</tr>
<tr>
<td></td>
<td>FL (H) *</td>
<td></td>
<td></td>
<td>ML (L) *</td>
<td></td>
</tr>
<tr>
<td>Corrected Arm</td>
<td>FL (H) *</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm Flexed</td>
<td>FL (H) ***</td>
<td></td>
<td></td>
<td></td>
<td>MOC (L) ***</td>
</tr>
<tr>
<td>Forearm</td>
<td>FL (H) ***</td>
<td>FL (H) ***</td>
<td>FL (H) **</td>
<td>MOC (L) ***</td>
<td>MOC (L) ***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ML (L) ***</td>
<td>MWCS (H)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FOC (L) **</td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>FL (H) *</td>
<td></td>
<td></td>
<td></td>
<td>MOC (L) *</td>
</tr>
</tbody>
</table>

* p<0.05, ** p<0.01, *** p<0.001
MOC= Male open-class, ML= Male lightweight, MWCS= Male World Class Start
FOC= Female open-class, FL= Female open-class
<table>
<thead>
<tr>
<th>Morphological Characteristic (Girths)</th>
<th>Male Open-class (MOC)</th>
<th>Male Lightweight (ML)</th>
<th>Male WCS (MWCS)</th>
<th>Female Open-class (FOC)</th>
<th>Female Lightweight (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist</td>
<td>FL (H) *</td>
<td></td>
<td></td>
<td></td>
<td>MOC (L) *</td>
</tr>
<tr>
<td>Gluteal</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td>FOC (L) *</td>
<td>MOC (H) ***</td>
<td>FOC (L) **</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MWCS (H) *</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ML (H) ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FL (H) **</td>
<td></td>
</tr>
<tr>
<td>Thigh</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td></td>
<td>MOC (H) ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ML (H) ***</td>
<td></td>
</tr>
<tr>
<td>Mid Thigh</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td></td>
<td>MOC (H) ***</td>
<td>FOC (L) ***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ML (H) ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FL (H) ***</td>
<td></td>
</tr>
<tr>
<td>Calf</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td></td>
<td>MOC (H) ***</td>
<td>FOC (L) ***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ML (H) ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FL (H) ***</td>
<td></td>
</tr>
<tr>
<td>Corrected Calf</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td></td>
<td>MOC (H) ***</td>
<td>FOC (L) **</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ML (H) ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FL (H) **</td>
<td></td>
</tr>
</tbody>
</table>

* p<0.05, ** p<0.01, *** p<0.001
MOC= Male open-class, ML= Male lightweight, MWCS= Male World Class Start
FOC= Female open-class, FL= Female open-class

The z scores of the remaining girth measurements were not found to be significantly different between the five groups.
Table 3.6  Analysis of skeletal length, height and breadth z scores

<table>
<thead>
<tr>
<th>Skeletal Lengths, Heights and Breadths</th>
<th>Male Open-class (MOC)</th>
<th>Male Lightweight (ML)</th>
<th>Male WCS (MWCS)</th>
<th>Female Open-class (FOC)</th>
<th>Female Lightweight (FL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forearm</td>
<td>FOC (H) *</td>
<td></td>
<td></td>
<td>MOC (L) *</td>
<td></td>
</tr>
<tr>
<td>Billiocristal breadth</td>
<td>FOC (L) ***</td>
<td>FOC (L) ***</td>
<td></td>
<td>MOC (H) ***</td>
<td>ML (H) ***</td>
</tr>
<tr>
<td>Transverse Chest</td>
<td>FL (H) **</td>
<td>FL (H) *</td>
<td></td>
<td>FL (H) *</td>
<td>MOC (L) **</td>
</tr>
<tr>
<td></td>
<td>FOC (H) *</td>
<td></td>
<td></td>
<td>MOC (L) *</td>
<td>ML (L) **</td>
</tr>
<tr>
<td>A-P Chest Depth</td>
<td>FL (H) *</td>
<td></td>
<td></td>
<td>MOC (L) *</td>
<td></td>
</tr>
<tr>
<td>Humerus breadth</td>
<td>FL (H) *</td>
<td>FOC (H) *</td>
<td></td>
<td>MOC (L) *</td>
<td>ML (L) **</td>
</tr>
<tr>
<td></td>
<td>FL (H) **</td>
<td></td>
<td></td>
<td>MOC (L) *</td>
<td></td>
</tr>
</tbody>
</table>

* p<0.05, ** p<0.01, *** p<0.001

MOC= Male open-class, ML= Male lightweight, MWCS= Male World Class Start
FOC= Female open-class, FL= Female open-class

The z scores for the remaining skeletal lengths, heights and breadths were not significantly different between the five groups.
3.6 Association between 2km time and anthropometric variables

Numerical values can be calculated to show the relationship between two variables, but a useful visualisation is to plot the two variables on a scatterplot. Figure 3.6.1 below shows a typical scatterplot with the best straight line fit by linear regression technique. However in order to best quantify the direction of relationship and its strength, Pearson correlations were performed using SPSS for open-class males, lightweight males and for females to identify which physical variables had the strongest relationship with 2km time. The females were grouped together instead of being split into open-class and lightweight, due to the sample size being relatively small. This technique works best with only one independent variable; the stepwise regression below deals with the more realistic case of several independent variables.

For open-class males the strongest correlations with 2km time were with mid-thigh girth, muscle mass, gluteal girth and stretch stature. For lightweight males the strongest correlations with 2km time were with biiliocristal breadth and biepicondylar humerus breadth. For females the strongest correlations with 2km time were with ∑8 skinfolds, corrected forearm girth and Fat Free Mass.

\[ y = -0.1663x + 118.3 \]
\[ R^2 = 0.2139 \]

**Figure 3.6.1** Muscle Mass Versus 2km time in Open-class Male Rowers
The correlation between muscle mass and 2km time shown in figure 3.6.1 was found to be significant at the p<0.01 level, with a Pearson Correlation of -0.462.

The bivariate correlations between measured morphological characteristics and 2km time are presented in tables 3.7, 3.8 and 3.9. The characteristics displayed are those that have been shown to have a significant relationship with 2km time (p<0.05).

Table 3.7 – shows the Pearson correlation coefficients of measured morphological characteristics with 2km ergometer time in Open-class males.

<table>
<thead>
<tr>
<th>Morphological Characteristics</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid thigh girth (cm)</td>
<td>-0.403</td>
<td>=0.027</td>
</tr>
<tr>
<td>Muscle Mass (kg)</td>
<td>-0.462</td>
<td>=0.01</td>
</tr>
<tr>
<td>Stretch stature (cm)</td>
<td>-0.427</td>
<td>=0.019</td>
</tr>
<tr>
<td>Gluteal girth (cm)</td>
<td>-0.370</td>
<td>=0.043</td>
</tr>
</tbody>
</table>

Table 3.8 – shows the Pearson correlation coefficients of measured morphological characteristics with 2km ergometer time in lightweight males.

<table>
<thead>
<tr>
<th>Morphological Characteristics</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biiliocristal Breadth (cm)</td>
<td>-0.477</td>
<td>=0.033</td>
</tr>
<tr>
<td>Biepicondylar Humerus Breadth (cm)</td>
<td>-0.458</td>
<td>=0.042</td>
</tr>
</tbody>
</table>
Table 3.9 – shows Pearson correlation coefficients of measured morphological characteristics with 2km ergometer time in female rowers.

<table>
<thead>
<tr>
<th>Morphological Characteristics</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>∑8 skinfolds</td>
<td>0.479</td>
<td>=0.048</td>
</tr>
<tr>
<td>Fat Free Mass (kg)</td>
<td>-0.429</td>
<td>=0.033</td>
</tr>
<tr>
<td>Corrected Forearm girth (cm)</td>
<td>-0.520</td>
<td>=0.043</td>
</tr>
</tbody>
</table>

3.7 Prediction of 2km time by anthropometric data

SPSS was used to perform a stepwise regression to establish predictors of 2km time. This prediction model could then be used in similar groups of University rowers to predict 2km time. Therefore, the dependant variable was 2km time and the physical characteristics and training history were used as the independent variables.

For Male Open-class rowers (n=30):

\[
2\text{km time (s)} = 579.1 -1.5 \text{ (muscle mass)} - 0.16 \text{ (experience)} - 2.3 \text{ (A-R)}
\]

\[
(r^2 = 0.450, \text{SEE} = 13.90 \text{ seconds , } p = 0.0016)
\]

Where:

Muscle mass is in kg (see appendix V).
Experience is in months.
A-R is acromiale-radiale length in cm.

The equation above explains 45% of the variation in 2km times in University Open-class male rowers.
For Male Lightweight rowers (n=20):

\[
2\text{km time (s)} = 602.9 - 5.39 \text{ (sessions)} - 2.86 \text{ (corrected waist)} + 10.35 \text{ (humerus)} - 0.15 \text{ (experience)}
\]

\[
(r^2 = 0.570, \text{SEE} = 14.75 \text{ seconds}, p = 0.006)
\]

Where:

- Sessions are per week.
- Humerus and corrected waist girths are in cm.
- Experience is in months.

The equation above explains 57% of the variation in 2km times in University lightweight male rowers.

For Female rowers (n=22):

\[
2\text{km time} = 851.2 - 0.29 \text{ (experience)} + 1.49 \text{ (Iliiac Crest sf)} - 3.65 \text{ (Chest)} + 4.06 \text{ (Subscapular sf)} - 3.84 \text{ (Biliocristal)}
\]

\[
(r^2 = 0.89, \text{SEE} = 8.62 \text{ seconds}, p = 0.002)
\]

Where:

- Experience is in months.
- Iliiac Crest and Subscapular skinfolds are in mm.
- Chest girth and biliocristal breadth are in cm.

The equation above explains 89% of the variation in 2km times in University female rowers.
For Male and Female rowers (n=72):

\[
\text{2km time} = 553.2 + 48.2 \text{ (gender)} - 1.83 \text{ (muscle mass)} - 6.1 \text{ (experience)} - 2.75 \text{ (A-R)} + 9.12 \text{ (humerus)}
\]
\[
( r^2 = 0.82, \text{ SEE } = 16.67 \text{ seconds}, \ p = 0.017)
\]

Where:
Male = 0 and female = 1 for gender.
Muscle mass is in kg.
Experience is in months.
A-R is acromial-radiale length in cm.
Humerus breadth is in cm.

The equation for the pooled male and female data explains 82% of the variation in 2km times in University male and female rowers.
4.0 Methods and Materials– Experiment 2

4.1 Participants

Participants were recruited by advertising for volunteers by poster. All participants had previously been in crew boats which had utilised the TS, therefore had an understanding of what the TS could do and had experience of the calibration process.

4.2 Technique System

The TS was devised by Tim Baker at Precision Sport and has only been commercially available since 2006. It comprises the following items:

**On Board Computer**

The on board computer is approximately 8cm x 6cm x 6cm in size and has a display screen. This displays numeric information about the crew’s technique for every stroke that they row, in real time. Whilst the crew is on the water, the display can show the rower or the coxswain the following information for each stroke:

<table>
<thead>
<tr>
<th>Rating Ratio</th>
<th>Boat speed</th>
<th>Total stroke angle</th>
<th>Boat tilt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Peak speed</td>
<td>Catch angle</td>
<td>Washing out</td>
</tr>
<tr>
<td></td>
<td>Peak acceleration</td>
<td>Finish angle</td>
<td>Digging deep</td>
</tr>
<tr>
<td></td>
<td>Peak deceleration</td>
<td>Missed catch angle</td>
<td>Hands away speed</td>
</tr>
<tr>
<td></td>
<td>Catch speed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The display has large letters so that it can be read whilst rowing. The computer can be set to scroll through the above information so that an overall picture of the rowing technique can be observed whilst rowing, or it can be set to one particular screen if crew members are concentrating on one particular aspect of their stroke. The data collected are stored on a multi-media card which is fitted inside the on board computer and can be easily transferred to a PC or laptop computer for later analysis.
Blade sensors

The blade sensors are fitted beneath the top-nut of the rigger. Depending on the type and set up of the rigger, often a metal spacer is required to lift the sensor away from the moving oarlock. The arm of the blade sensor simply clips onto the inboard section of the oar.
**Boat Dynamics Sensor**

The dynamics sensor is attached to the inside hull of the boat with velcro strips. It is approximately 5cm x 3cm x 2cm in size and needs to be attached level as it measures the balance or tilt of the boat and forward acceleration. (A boat speed sensor can be supplied by the manufacturer, but was not available for this work).

![Boat Dynamics Sensor](image)

**Figure 4.3** Boat Dynamics Sensor

**PC Analysis Software**

The Precision Sport software (V1.3.1) allows for a greater depth of analysis of the outing than the onboard computer allows whilst the crew is on the water. This can be done immediately following an outing. This is useful as it allows the coach and crew to appreciate relationships between the measured parameters and their performance during a session. A 3D image of the crew is generated via the Virtual Video and it allows the outing to be replayed in real time, in slow motion, and to fast forward and to pause. Rating, ratio, acceleration, speed variation and tilt are shown graphically for every stroke. For each individual rower, for every stroke of the outing, catch and finish angles are displayed as well as catch timing, catch speed, missed stroke angle, washing out, digging deep, and the amount of tap down at the finish. The software allows for a certain degree of statistical analysis. Sections of the outing can be selected and the boat and rower data for this section can be averaged. This is of use because rowing is a cyclic sport – in a session the athlete may take many hundreds of strokes, therefore it can be more useful to convert this large amount of data into a single stroke cycle which
represents that session or part of the session.

4.3 Study Design

Six experienced female scullers completed the test protocol in single sculls, but further measurements were not possible because the TS developed a fault and had to be returned to the manufacturer for repair. Each volunteer completed at least one practice session in their own single scull to familiarise themselves with calibrating the technique system prior to the testing.

4.4 Data Collection

Data were collected from the six participants over the course of a two day period when the weather and water conditions were calm. The participants completed the test protocol one at a time, with the test protocol taking about two hours per participant to complete. This involved the participants completing the same set of strokes at the three foot stretcher positions; natural, to the stern and to the bow. The ‘natural’ stretcher position was defined as the athlete’s self selected stretcher position which they were used to training with; the stern position was 4cm towards the stern from the natural stretcher position and the bow stretcher position was 4cm towards the bow from the natural stretcher position (4cm was the chosen change as preliminary testing showed that it produced a measureable effect without disrupting the normal rowing stroke). The stroke pattern which they had to follow was 3 x 30 strokes at rating 18, 24 and 30 strokes/min, doing 30 strokes at full pressure and 30 strokes at half pressure twice (trial one and trial two) in each stretcher position. This meant that overall each participant was taking 540 strokes at firm pressure which is broadly comparable to completing two 2km races at firm pressure, which was well within the capability of these participants.

Other details of boat and blade set up were recorded at this time including span, inboard length, total oar length and pin-stretcher distance. A balanced experimental design was used with one third of participants starting in their natural stretcher position, one third starting with the stretcher towards the stern and one third starting with their stretcher towards the bow. This was done to reduce any ordering effect and to minimize the effect of fatigue.
The athlete is required to follow a simple calibration process at the beginning of the outing. This is necessary to establish water level relative to the rowers’ blades. Firstly, the athlete is required to sit the boat level to calibrate the tilt sensor and accelerometer. The athlete is prompted to sit the boat level, with no movement and the computer gives a countdown over 4 seconds and then the computer takes the reading to establish the boat level condition. Next, the blades need to be placed square in the water for the second water calibration to be taken to establish the correct depth of the blades. In a single scull, the bowside and strokeside blades are done separately. Again the computer gives a countdown to allow the athlete to get into the correct position. The entire spoon of the blade should be covered with the top edge of the spoon in line with the water line. Additionally in this experiment, the horizontal position of the boat dynamics sensor was checked with a spirit level each time the system was set up.

4.5 Data Analysis

The Precision Sport software was used to analyse the data. Of the 30 strokes at firm pressure, only the middle 20 strokes were used in the analysis to allow the athlete time to get the boat moving and to settle into rhythm. The sculler’s peak acceleration was then averaged out for the 20 strokes using the Precision Sport software.

The results from Trial one and Trial two for each participant were analysed in a paired samples t test. The protocol was set up in this way with test – re-test to confirm the repeatability of the test and the reliability of the results with a Bland and Altman (1995) analysis.
5.0 Results – Experiment 2

5.1 Acceleration

Figure 5.1 taken from the Precision Sport software shows a typical graph of acceleration versus time % through the stroke. The early peak corresponding to the maximum of the drive phase at about 30% is predicted by Nolte (1991) and by equation 2. From about 40% - 75% acceleration remains positive but at a very low value. This is the result of the conservation of momentum – as the athlete enters the recovery phase and slides in a rearward direction, the boat plus athlete system momentum requires the boat to accelerate forwards (Baudouin, 2004). From 75% - about 8% of the following stroke, boat drag dominates and the boat decelerates.

![Figure 5.1 Acceleration versus time throughout rowing stroke.](image)
5.2 Peak acceleration versus stretcher position

Figure 5.2 shows average peak acceleration over 20 strokes versus stretcher position plotted for each of the six participants. No significant differences were found between Trial 1 and Trial 2.

![Figure 5.2 Peak Acceleration versus Stretcher Position](image-url)
5.3 Data Analysis

Table 5.1 gives details of the participant’s stature, body mass and the maximum peak acceleration that was achieved throughout trials 1 and 2. Due to measuring constraints, stature and body mass were the only morphological data measured.

Table 5.1

<table>
<thead>
<tr>
<th>Participant</th>
<th>Stature (cm)</th>
<th>Body Mass (kg)</th>
<th>Peak Acceleration (m/s/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 1</td>
<td>176</td>
<td>58.3</td>
<td>4.10</td>
</tr>
<tr>
<td>Participant 2</td>
<td>173</td>
<td>74.8</td>
<td>4.43</td>
</tr>
<tr>
<td>Participant 3</td>
<td>179</td>
<td>70.2</td>
<td>5.12</td>
</tr>
<tr>
<td>Participant 4</td>
<td>175</td>
<td>66.1</td>
<td>4.40</td>
</tr>
<tr>
<td>Participant 5</td>
<td>167</td>
<td>56.0</td>
<td>3.72</td>
</tr>
<tr>
<td>Participant 6</td>
<td>174</td>
<td>63.0</td>
<td>4.93</td>
</tr>
</tbody>
</table>

Regression analysis was performed to obtain a prediction model for peak acceleration based on stature and body mass.

\[
\text{Peak acceleration} = -10.43 + 0.77 \times \text{(stature)} + 0.24 \times \text{(body mass)}
\]

\[r^2 = 0.64, \text{SEE} = 0.39 \text{ m/s/s}, p = 0.21\]

Where:

Acceleration is in m/s/s.
Stature is measured in cm and body mass in kg.

The equation above explains 64% of the variation in peak acceleration in female single scullers.
6.0 Discussion

6.1 Experiment 1

Data from experiment 1 were analysed by four different means, as follows:

6.1.1 Somatotype

Both male and female somatoplots showed a distinctive pattern, with most athletes’ data points lying approximately on a straight line of slope -1 passing through the origin (X=Y=0), more noticeably for females than for males. Indeed when a straight line is fitted to this somatoplot, the $r^2$ figure is 89.4% for males and 94.3% for females. The X, Y co-ordinates of each point are:

\[ X = \text{ectomorphy} - \text{endomorphy} \]
\[ Y = 2 \times \text{mesomorphy} - (\text{endomorphy} + \text{ectomorphy}) \]

If we treat these as simultaneous equations and eliminate ectomorphy as follows,

Ectomorphy = X + endomorphy

Therefore,

\[ Y = 2 \times \text{mesomorphy} - (\text{endomorphy} + X + \text{endomorphy}) \]
\[ Y = 2 \times \text{mesomorphy} - 2 \times \text{endomorphy} - X \]

This is a straight line of slope -1 and passes through the origin if and only if mesomorphy=endomorphy. For females in particular, it is therefore concluded that for these participants, the mesomorphy score closely approximated their endomorphy score, that is for the more muscular individuals the greater their relative fatness. For males, the more mesomorphic individuals follow this straight line relationship less closely, and these more muscular individuals tend to be less endomorphic. This trend is also observed by Carter (2002) where Australian female athletes’ somatotypes fall clearly on the straight line described, whereas Australian male athletes are less endomorphic and their data points lie above this line. When interpreting the somatoplots of top ranked and lowest ranked males in this study, it can be seen that the higher placed male rowers tend to be towards the mesomorphic type with their plots towards the top left of the
somatochart; these individuals are less endomorphic than average, which may account for their high performance. The lower performers tend to be more ectomorphic – towards the bottom right of the somatochart. This finding is valid for both the Open-class and lightweight male athletes. The surprising finding that the faster male athletes are also towards endomorphy may be explained by the fact that it is widely noted on an informal basis that additional mass is in fact an advantage (only on the ergometer) as a heavier person can generate more force whilst leaning back towards the end of the stroke.

For females this observation is reversed with the higher placed individuals tending towards ectomorphy and the lower placed individuals tending towards mesomorphy. However it has been noted these more mesomorphic individuals also tend towards endomorphy and it may be that this extra adiposity accounts for the reduction in performance. There was one outlying female who had a very unusual body type – she was very muscular but extremely fat and did not conform to the pattern of the other females.

### 6.1.2 Z Scores

In the present investigation, mean z scores for skinfolds showed that lightweight rowers consistently had lower skinfold readings than Open-class athletes in both males and females. The WCS athletes were found to have the highest proportional skinfolds, which could be attributed to the fact that they had only been rowing for one year since being identified. Additionally, Open-class, lightweight and WCS athletes tended to have negative z scores for skinfold readings showing that their skinfolds were proportionally lower than the phantom. This could be attributed to the nature, duration and intensity of rowing training which over time will tend to lead to reduced adiposity. When a one way ANOVA was completed to determine significant differences in skinfold z scores between the groups the Open-class females were found to have significantly higher readings for all eight skinfolds than both the Open-class and lightweight males. The fact that women possess a greater body fat than men is well documented – women require this additional fat in order to menstruate and this extra adiposity is essential to support a successful pregnancy. These Open-class females were also found
to have significantly higher measurements than the lightweight females for four of the skinfold readings.

The z scores for girth measurements showed distinct differences between the male and female groups. Indeed, the Open-class male readings were found to be statistically significantly different to either the female Open-class or female lightweight athletes in twelve out of thirteen girth measurements. All three male groups tended to shadow each other closely with very small differences however the females showed greater variation in results, although with a tendency to follow the same general pattern. All groups showed a peak for corrected arm and calf girths which could also be attributed to the specific nature of rowing training.

The z score diagrams for skeletal dimensions showed up more distinct differences between the groups. Male WCS athletes are shown to have a proportionally large trochanterion to tibiale laterale length and small biiliocristal breadths. In the current investigation, the z-scores for female, male, lightweight, Open-class and WCS athletes tend to shadow each other although the Open-class athletes are consistently towards the right of lightweights (more towards positive i.e. are proportionally larger), which is expected. However, shoulder breadth was one of the few points where the lightweights were approximately as proportionally large as the Open-class athletes, and the female Open-class athletes had statistically significantly proportionally broader shoulders than both the Open-class males and the lightweight males. When eyeballing graph 3.5.5 it is seen that this is where the WCS male athletes differ from the rest of the male rowers with their proportionally long skeletal lengths in the lower body.

6.1.3 Pearson Correlations

In Open-class male rowers in this investigation, 2km time was most closely correlated with muscle mass \((r=-0.46)\) and stretch stature \((r=-0.42)\). In lightweight males in this investigation 2km time was most closely correlated with biiliocristal breadth \((r=-0.48)\) and humerus breadth \((r=-0.46)\). It is perhaps unsurprising that for Open-class men the important factors are ones of absolute size and bulk (including stature, muscle mass and mid-thigh girth) and that this is not the case for lightweights who have a
weight restriction to meet. Therefore, for lightweight male rowers it has been found that an improved performance can only be associated with dimensions of the skeleton rather than measures of bulk and muscularity. In females in this investigation 2km time was found to be correlated with measures of body fat and muscularity, including sum of skinfolds ($r=0.48$), fat free mass ($r=-0.43$) and corrected forearm girth ($r=0.52$).

### 6.1.4 Regression

When a regression was performed in Open-class males, muscle mass, experience and upper arm length were found to explain 45% of the variation of 2km time in this population; no other variables made a large contribution to explaining variation. In lightweight males, the most relevant variables in the regression were experience, the number of training sessions per week, waist girth and humerus breadth and together these explained 57% of the variation in 2km times. In females, a variety of skinfold, girth and breadth characteristics came together to explain 89% of the variation in 2km times in University female rowers.

Although the regressions performed in the current investigation only explain part of the variation in 2km performance there were many contributory variables which were outwith the scope of this investigation, therefore were not measured. For example, factors such as the athletes maximal oxygen uptake, anaerobic threshold, maximal force, maximal power (Ingham et al. 2002), flexibility, ratio of drive phase to recovery phase (Graham Smith et al. 2006) and the ratio of free testosterone to cortisol (Jürimäe and Jürimäe, 2002) which have all been shown by other authors to contribute to 2km ergometer performance were not measured. However, it has been reported that anthropometric variables are the best predictors of 2km ergometer performance (Russell et al. 1998) therefore even if the scope of the current investigation had been far larger to incorporate physiological, technical and psychological factors it may not have been possible to explain much more of the variation in 2km ergometer performance.

### 6.1.5 Relationships Between Somatoplots, Z Scores, Regression Analysis and Pearson Correlations
The somatoplots, z scores, regressions and Pearson Correlations are all based on the same data and so should exhibit the same general trends. This is indeed the conclusion: in particular, the most successful female rowers have relatively low skinfold measurements, the most successful male Open-class rowers had strong musculature and long extremities, and the most successful male lightweight rowers had a broad skeletal measurements. These features do appear in all 4 of these analysis techniques, where relevant.

### 6.2 Experiment 2 – Technique System

Positioning of the foot stretcher can optimise the work angles of the knees and ankles to enable the athlete to gain maximum efficiency out of the leg drive (Redgrave, 1995). The optimum stretcher position will allow the optimum catch and finish angles by positioning the athlete relative to the pivot point of the pin. “There is no universal set-up that will enable maximum transfer of power from the rower to the boat. It has to be determined on an individual basis” (Oarsport, 2008).

A simple biomechanical model of leg extension and water stroke/oar interaction (see Section 1.8.3) suggests that there is an optimum foot stretcher position which gives highest peak acceleration. It was found that foot stretcher position does indeed have an effect on peak acceleration and for one subject (of six) clear evidence of a peak in performance was found. For five participants, results indicate that their normal stretcher position does not give optimum peak acceleration. This is not to conclude that any of these stretcher positions is the overall optimum as the biomechanical model used is simplistic and there are many other biomechanical, physiological and psychological factors which may bear on real race performance. But the potential for the technique system to measure performance and to assist in the optimisation of boat set up is clearly demonstrated. In the past, a coach could only rely on trial and error to apply rigging changes and the effects of such empirical trials throughout the year could hinder the rower’s performance (Nolte, 2005) therefore by using the TS this lengthy process of trial and error could be eliminated.

It is also concluded that the TS is an effective tool for measurements of boat peak acceleration. Changes in stretcher position were predicted to affect
peak acceleration and it was indeed found that the TS could measure this effect. Therefore the TS shows real promise as a tool to optimise boat set-up.

### 6.3 Principal Findings

The present investigation found an association between body morphology and 2km time on the rowing ergometer in a cohort of Scottish University level rowers. More specifically for Open-class men, the most significant morphological characteristics are those of size and muscularity, with muscle mass, mid thigh girth and stature among the strongest correlations with 2km time. Differing from this finding for Open-class men, for lightweight men it has been found that the dimensions of the athlete’s skeleton appear to have a greater effect on performance, with billiocristal breadth and biepicondylar humerus breadth playing an important role. In females low body fat (as assessed by $\Sigma$ of skinfolds) and high Fat Free Mass were associated with an improved performance, as was a greater corrected forearm girth.

In the second experiment, it was shown that greater stature and greater body mass led to a greater peak acceleration in the on-the-water situation.

It is therefore considered that the basic hypothesis is supported. Large stature and muscle mass confer an advantage as predicted by a simple biomechanical model. Measurement results in both experiment 1 and 2 support these conclusions.

### 6.4 Discussion of principal findings in relation to other studies

#### 6.4.1 Somatotype

**Males**

Below is a somatoplot showing the mean somatotype ratings for male Open-class and lightweight rowers in the current investigation as well as male rowers from other studies.
The athletes in the current investigation (especially the lightweights) are shown to tend towards ectomorphy when compared with the rowers from the other investigations. This could be attributed to the fact that most participants in this investigation were undergraduate students aged between 18 and 24 years of age so are not fully matured. The athletes studied by Kerr et al. (2007) were competing at the Sydney Olympics so would be expected to be more mesomorphic than a cohort of undergraduate students. It is interesting to note that the scattering observed in the above somatoplot is very similar to that in section 3.4.1.
Females

Below is a somatoplot showing the mean somatotype ratings for female rowers in the current investigation as well as females from other studies.

The distribution of female somatotypes described in the current investigation is somewhat similar to that found by Battista et al. (2007) who were
investigating anthropometric characteristics of female collegiate athletes. This is the study which the most similar group of rowers in terms of experience and age, therefore it consolidates the findings from this investigation. The average somatoplot of Hebbelinck et al. (1980) and the Open-class athletes studied by Kerr et al. (2007) overlaps which is rather interesting. The study by Hebbelinck et al. (1980) from the Montreal Olympics was before FISA split female rowing into Open-class and lightweight categories so seems to confirm that successful athletes before this time were built like Open-class athletes as opposed to lightweight athletes.

6.4.2 Z-score

In the current investigation, z-scores tend to mirror each other across the groups. This is also found in the study by Kerr et al. (2007) where the Open-class and lightweight groups shadow each other with the Open-class line slightly to the right. However, this is not the case for body mass, which is much higher proportionally in Open-class athletes; this is to be expected as they have no weight restriction. Slater et al. (2005) also found the Under-23 age category athletes to mirror the open age category athletes very closely in all measures except in the measures of muscularity whereby the older athletes were much proportionally larger.

The male WCS athletes in this study have proportionately large trochanterion to tibiale lengths, small biiliocristal lengths and large front thigh skinfolds, which is shown in literature to be the pattern of elite rowers (Kerr et al. (2007); Hebbelinck et al. (1989)).

It has been shown in literature that lightweight rowers do not differ much in stature and build from non-rowing population (De Rose et al. 1989). Similarly, this investigation has found male lightweight athletes z scores to be close to zero in most measures (with the exception of skinfolds which are all low) which means that these athletes are somewhat similar to the phantom. Lightweight rowers have been found to have proportionally broader shoulders than Open-class athletes (Kerr et al. 2007) – although this was not quite the case in the present investigation this was one of the very few points on the z score graph where the lightweight and Open-class males had a very similar reading rather than the Open-class males being much larger.
All groups in this investigation had peaks for corrected arm and calf girths. Similar findings were made by Hebbelinck et al. (1980) who found that when scaled to the phantom rowers had much larger flexed arm and forearm girths than the control group.

### 6.4.3 Regression

Findings in this study differ somewhat from those by Graham Smith et al. (2006) who found that the greatest predictive power came from studying the athletes peak power – this gave 75% of variation in performance, and was linked directly to stretch stature as a longer stroke is more biomechanically efficient as a taller person can apply force over a greater distance. Stretch stature accounted for 60% and body mass for 29% of variation in 2km performance time in the study by Graham Smith et al. (2006). Stature was found to be correlated with 2km ergometer time in this investigation in Open-class males ($r=-0.43$, $p<0.019$).

This emphasises the importance of height, as a taller person can apply force over a greater distance – therefore applying a greater overall energy per stroke.

### 6.4.4 Pearson Correlation

Yoshiga et al. (2003) found in general that as body size increased, so did rowing performance. 2km time in 18-24 year olds was found to be correlated with stature ($r=-0.81$) and body mass ($r=-0.85$) $p<0.001$. The present study found parallel findings in both male Open-class and male lightweight rowers where measures of muscularity and size were positively correlated with 2km performance.

In the Hazewinkle Anthropometric Project in 1997, Bourgouis et al. (2001) found female rowers to be in the 93rd percentile for body mass and in the 97th percentile for stretch stature. They were on average 7% taller and 25% heavier than age-matched Belgian girls. The boys in this study were found to be 7% taller and 27% heavier than age-matched Belgian boys (Bourgouis et al. 2000). Jurimae and Maestu (1999) found 2km time to be correlated with stature ($r=0.71$), body mass ($r=-0.91$) and muscle mass ($r=-0.85$) all at
Although the current investigation did not find an outright correlation between 2km ergometer performance and body mass some other variables which could be considered surrogates for body mass (muscle mass, girth and breadth measurements) were found to correlate with 2km ergometer time. This could be considered a similar finding as performance was increased with body size.

6.4.5 Technique system

Graham-Smith et al. (2006) found rowing performance to be highly associated with peak power – indeed it accounted for 75% of variation in 2km and 5km ergometer times. Additionally stature has been found to correlate with peak power (r=0.67, p<0.01) (Graham-Smith et al. 2006). In the present investigation, there was a positive correlation between stature and peak acceleration, and the tallest athlete was found to have the highest peak acceleration. Although the relationship between peak power and peak acceleration is undefined (acceleration is proportional to force, power is force x handle speed), it is highly suggestive that both power and acceleration show associations with stature.

6.5 Strengths of the study

All participants in Experiment 1 were competing at a national level indoor event, therefore there was a very good atmosphere on the day and a strong motivation to do well. For those participants who were aiming for Scottish selection, this was a mandatory event and the 2km time is used in the selection criteria, which also would have added to the athletes’ motivation to do their best on the day.

Although 14 days were allowed for data collection, in practice all of the anthropometric measuring was completed within 7 days of the events, with 41% of participants being measured on competition day. This was a real strength of this study as it reduces the potential for weight loss, weight gain or changes in body composition between the 2km test and the anthropometric testing.

Experiment 1 has 72 participants, which is more than many of the previous research studies in rowing (reviewed in chapter 1). Rowing is a minority
sport in Scotland and 72 University participants represents a large percentage of active Scottish University rowers at this time. This wide base of participants means that the results may be valid for all Scottish University rowers. This study encompasses male, female, lightweight, Open-class and WCS athletes.

An additional strength of this study is the rigour of the anthropometric measurements. A full ISAK proforma was taken for each participant which gives a good overall picture of that person’s morphology. Several of the studies reviewed in chapter 1 did not use the full proforma: for example in the Graham-Smith et al article the anthropometric data consisted only of height and body mass. Although care has to be taken to avoid spurious results when analysing so many measurements, it does give a much more thorough investigation than if only a handful of anthropometric measures had been taken. All measurers were Level 2 ISAK trained anthropometrists and their measuring was standardised against a Level 4 ISAK criterion anthropometrist.

All 2km ergometer times were taken directly from the official Concept 2 race results after the Championships. The event organisers conduct a very strict procedure for accessing and recording the times, therefore these data were very reliable. Although only 4 WCS athletes were measured, it has been very interesting to have their data to compare to the rest of the groups.

Although the scope of Experiment 2 was limited, the six scullers were all experienced competitive athletes with experience of using the TS. The experimental design with the test-retest design ensured that the results were repeatable. Ordering effects were also minimised.

6.6 Weaknesses of the study

In Experiment 1, no non-rowing control group was used to compare rowers with the general population or with non rowing athletes. The primary aim was to assess how 2km performance of experienced rowers is related to morphology, and it would have been irrelevant to have non-rowing control participants completing an all-out 2km race on the ergometer.
Regression was used in the analysis section which came out with interesting findings, however regression is really best used with a much larger sample size. This means that the prediction model may not transport well into other rowing populations. A second problem with regression is colinearity, for example due to the nature of the data, several of the measures are sums of other measures. For example, stature is approximately the sum of iliospinale height plus sitting height. To account for this and to reduce the effect of colinearity a stepwise regression was used.

A possible weakness of this study was the differing levels of experience within the participant group. However, all participants had at least 1 year of rowing experience. As rowing is an emerging sport in Scottish Universities, participants purely had to be drawn from a limited pool of Scottish rowers, of necessity taking people of differing experience levels: however, this greatly increased participant numbers helping to increase the value of the study.

No control protocol prior to the all-out 2000m ergometer test was imposed (such as zero exercise for 24 hours and zero eating for three hours prior to the event). It would have been unethical to dictate a protocol for the athletes to follow prior to an event which counted towards National selection however all participants would have been given advice from their coaches in the best preparation for a race.

Similarly, in Experiment 2 no non rowing controls were used. The small sample size of participants and the use of only three stretcher positions were also limitations.

6.7 Meaning and implications

The overall objective to investigate morphological characteristics of successful Scottish University rowers was achieved; the findings broadly agree with the groundswell of opinion (and back up data collected from elite rowers) that successful rowers are taller and have greater girth and breadth measurements than less successful rowers or non-rowers. Similarly, the second objective of the investigation was realised – the TS proved a useful tool and maximal peak acceleration in a single scull was found to be related to stature and mass.
In Open-class males the key morphological dimensions are shown to be those of muscularity and stature. In lightweight men, breadth dimensions of the athlete’s skeleton appear to have a more significant role in predicting 2km ergometer performance. Because lightweight males are likely to be bunched just below the cut off weight, it is recognised that they are a much more homogenous group than Open-class males, so their stature and muscularity are likely to be more similar than would be the case with Open-class athletes. Hence other aspects of their morphology will play a proportionally bigger role. In female rowers, the key morphological factors are those of adiposity. These differences between the key muscular, skeletal and adipose characteristics of successful rowers go some way to explaining the differences in performance between the sexes. The muscular and skeletal make up of men which has been shown in this investigation to correlate with 2km ergometer time goes some way to explaining why males are faster at rowing on the ergometer than females.

It has been found that the somatotype for both male and female Scottish University rowers (whether lightweight, Open-class or WCS) falls along a straight line, as with the Australian athletes described in a study in by Carter (2002). However, the top ranked male and female athletes in the current study exhibited opposite trends, with high performing males tending towards endomesomorphy and females towards ectomorphy which again may go some way to explaining why males are generally faster at rowing on the ergometer than females. The females show a slightly greater scatter in the somatoplot than the males although the females exhibited less scatter in terms of performance time.

It was perhaps surprising that, with the exception of stature, most measures of skeletal lengths did not have significant relationships with 2km ergometer time (although the biomechanical model predicts that leg length should be a significant factor). Skelic and brachial indicies were calculated but no significant relationship was found with 2km time. This could be attributed to the fact that performance was measured on the ergometer rather than on the water where skilful technique plays less of a role, with other studies showing muscularity and fitness to be key factors. In females, the key morphological characteristics associated with improved performance were those of low fat.
mass. This could be attributed to rowing training leading to a decreased body fat (non-athletic females tend to have higher body fat than athletic females), therefore those who are fitter, stronger and faster on the rowing ergometer have likely performed more training and therefore have lost body fat.

Models were developed to predict 2km rowing performance on the basis of body morphology. The application of these models could be to test whether current rowers are achieving the performances that they are predicted to be capable of or alternatively to identify talent within the population of Scottish University students who the results of the current investigation may transfer over to.

With regards to comparing Open-class, lightweight and WCS rowers the one-way ANOVAs plus pairwise comparisons of means of Z scores results showed up particular differences between the Open-class males and the Open-class females. The male and female groups showed far less internal difference than when the male and female groups were compared to each other. However, it was not possible to discern any relationship between high performers and their individual z-scores.

Although there were only four WCS athletes participating in this investigation, it was interesting to observe that the WCS males in particular were morphologically similar to elite rowers; indeed they were more similar than the Open-class and lightweight rowers than just stature and arm span, the criteria on which they are selected; note that arm span was not found to be a determinant of success in this study so it is not clear why arm span is used to select WCS candidates. The WCS athletes were all in their first year of rowing and are showing a lot of potential but the real question is whether or not this can be realised. It is expected that WCS athletes have the morphological characteristics needed to make them champions, or they would not have been selected onto the programme. Therefore, whether they succeed or not seems to rely on factors other than their morphology such as mind-set, commitment and the prevention of injury. In an informal discussion with a WCS coach it was discovered that he had observed that the factors which seem to determine whether an individual is capable of staying with the programme are those that are very difficult to measure in the selection process – mental strength and a drive to be the very best. The
WCS athletes in this investigation were all relatively young (between 18 and 19 years of age) therefore it is possible that they were still growing as well as developing their fitness and technique, making their ultimate performance harder to predict. An implication may be that different selection criteria need to be used and that the current system should be appraised to assess whether it is possible to pick out future Olympians based on their stature and armspan.

On-the-water performance measurements with the TS support the view that particular body types lead to higher peak acceleration, though because of practical limitations boat speed was not measured and only female athletes’ stature and body mass could be measured. Although there is no literature in peer reviewed journals using the TS, it was discovered that it is a highly useful instrumentation system which shows real promise in optimising the stretcher position and boat set up.

Overall, the ideal physique is shown by this study to be characterised by tall stature, muscularity, broad skeleton and small skinfold readings. To a considerable extent, these characteristics are inborn (for example, there is no obvious way of training an athlete to be taller). However some characteristics can probably be improved by targeted training (for example to increase muscle bulk); so potential high performers are partly born, but partly made; there are insufficient data in this study to partition performance between these two factors.

It has been shown that measurements of body morphology are practicable on rowers in a competitive environment, and that these measurements can provide useful predictions of rowing performance as assessed by two different measurement techniques. It has been shown that the body types of Scottish University level rowers are similar in many ways to those of elite rowers. This could lead to a simple means of identifying future high performers at an early stage, so that they can be directed into the sport for which they are particularly well suited, and the WCS programme is a move in that direction.
6.8 Directions for future research

Some of the groups (female lightweights in particular) were very small, and experiments on larger groups would enable more certainty in the statistical analysis, especially with some of the more subtle effects.

The addition of a boat speed sensor to the TS (although the manufacturer can supply such a device, none was available for this project) would increase the amount of data available and add to the capability of this system. Although not explored in this project, the consistency of the data that were gathered suggests that the TS would also be useful in assessing and optimising rowing technique and used as a coaching tool to look at re-appearing trends in the crews technique on a stroke by stroke basis, potentially including real-time feedback to the athletes.

It is possible that a more holistic approach to studying performance may yield better results in terms of creating a prediction model for performance. If physiological, psychological and anthropometric variables were all investigated together it may be able to use a regression to explain a greater proportion of performance than was found in this investigation.
6.9 Overall Conclusions

In conclusion, relationships were discovered between body morphology, 2km ergometer performance and peak acceleration in a single scull. Specifically:

- When ranked by 2km ergometer time, top ranked males tend towards mesomorphy lying above a line of slope -1 and top ranked females tend towards ectomorphy.
- In Open-class males greater muscle mass and stature are associated with improved 2km ergometer performance.
- In lightweight males greater biiliocristal and humerus breadths are associated with improved 2km ergometer performance.
- In females, 2km ergometer performance is most closely correlated with sum of eight skinfolds ($r=0.48$), fat free mass ($r=-0.43$) and corrected forearm girth ($r=0.52$).
- Regression can be used to explain 45% of variation in Open-class males, 57% of variation in lightweight males and 89% of variation in females in relation to 2km ergometer time.
- Greater stature and body mass lead to a greater peak acceleration in a single scull.
- The TS is a useful tool with potential for the optimisation of boat set-up.
7.0 References


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8.0 Appendices

APPENDIX I – ROWING DEFINITIONS
APPENDIX II – INFORMATION SHEET FOR PARTICIPANTS
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Appendix I – Rowing Definitions

Backstops – The end of the slides nearest the bow of the boat. Also used to describe the position of the athlete when their legs are straight and the blade handle is to their chest.

Blade – oar including its handle, shaft and spoon.

Body angle – The degree of forward lean of the athlete’s body from the hips.

Bow – The end of the boat which travels through the water first.

Button – The plastic ring around the sleeve of the oar which prevents the oar from slipping through the oarlock.

Catch/Beginning – The moment at which the spoon is immersed in the water and propulsive force is applied. The athlete is at frontstops.
Cox – The team member who does not row but who steers the boat with a rudder.

Digging deep – when a portion of the *shaft* of the oar is under water during the *drive phase* of the stroke. Only the *spoon* of the oar should ever be in the water.

Drive phase/Power phase – Between the *catch* and the *extraction*.

Extraction – Removal of the *spoon* from the water by downwards pressure on the oar handle. The athlete is in the *backstops* position.

Feathered blade – Describes the oar when the *spoon* is horizontal.

Finish – The last part of the stroke where the handle is drawn into the body.

Frontstops – The end of the slides nearest the *stern* of the boat. Also used to describe the position of the athlete when they are about to take the *catch*, shins should be vertical.

Full pressure – When an athlete is rowing at their maximum capacity.

Gearing – The ratio of *inboard* to *outboard*. This determines how ‘heavy’ the rowing will feel.

Half pressure – When an athlete is rowing at half of their maximum capacity.

Inboard – the portion of the oar between the *button* and end of the handle.

Missing the catch – When the rower begins the leg drive before the catch is reached and the spoon is buried.

Oarlock – The plastic lock mounted on the *pin* of the *rigger* which attaches the oar to the boat.

Outboard – the portion of the oar between the *button* and the end of the *spoon*. 


Orthogonal – a line perpendicular to the line of the boat.

Pin – The part of the rigger which sticks up vertically. The oarlock is mounted and swivels on the pin.

Pitch – The angle of inclination of the spoon to the vertical during the propulsive phase of the stroke. This is dictated by both stern and lateral pitch.

Recovery phase – Between the extraction and the catch, the spoon is out of the water.

Rigger – Metal outrigger bolted onto the shell of the boat. Supports the swivel and the pin.

Rating – Number of strokes per minute.

Ratio – The ratio of the time taken for the power phase to the time taken for the recovery phase.

Single scull – A boat for one person.

Stretcher – A metallic or carbon plate inside the boat to which the shoes are attached. The stretcher is secured with screws and allows the rower to adjust their physical position relative to the oarlock.

Spoon – The cleaver shaped end of the oar which goes in the water.

Shaft/Loom – The long carbon part of the oar between the spoon and the handle.

Sleeve – A plastic collar around the shaft of the oar where the oar sits in the oarlock. Aids with squaring and feathering of the blades.

Stern – The end of the boat which travels last through the water.
Square blade – Describes the oar when the spoon is vertical.

Washing out – When the oar slips out of the water during the propulsive phase of the stroke producing a puddle of white water and losing boat speed.
Participant Information Sheet

I am inviting volunteers to consider taking part in an investigation into determinants of successful rowing performance in terms of body morphology and stretcher configuration. This is part of a Master’s research project sponsored by The Henley Steward’s Charitable Trust and supervised by Dr Arthur Stewart of the Robert Gordon University. Body morphology shall be measured using standard International Society for the Advancement of Kinanthropometry (ISAK) procedures. On-the-water performance shall be measured by the newly available Technique System made by Precision Sport. The objectives of this study are:

Experiment 1: To predict 2km rowing performance on the rowing ergometer on the basis of body morphology (including proportionality, musculature, adiposity and size).

Experiment 2: To investigate the influence of stretcher position on single sculling technique.

If you agree to participate, you will be asked to:

- Complete a session in a single scull with the foot stretcher in 3 different positions.
- Complete a 2km ergometer test (at the Scottish Indoor Rowing Championships).
- Have anthropometric measurements taken (measurements of body dimensions using a tape measure, sliding ruler and skinfold callipers). These measurements take about an hour to complete and include:
  - Weight
  - Height and sitting height
  - Skeletal lengths of the arms and legs
  - Skeletal breadths of the shoulders, pelvis, thorax, elbow and knee
  - Skeletal girths of the arms, legs and torso
  - Skinfold measurements at 8 sites on the arm, leg and torso
You would be required to wear shorts, a loose fitting T-shirt and in the case of females a sports vest. All measurements will be taken by a level 2 ISAK trained anthropometrist. All measurements will be taken in a private area.

All data shall be held in the strictest of confidence and any published data shall not identify individual participants.

Volunteers are free to withdraw at any time without giving an explanation. Volunteers will not be paid for taking part in this study but may be interested to find out their results. This study has been approved by the RGU ethics committee.

**Thank you for considering taking part in this study.**
For more information please contact Morag Emery on 0775 974 **** or at m.emery1@rgu.ac.uk
Physical Activity Readiness Questionnaire

- Do you have a heart condition? □ YES □ NO
- Do you feel pain in your chest when you do physical activity? □ YES □ NO
- In the past month, have you experienced chest pain when you were not being physically active? □ YES □ NO
- Do you lose your balance due to dizziness or do you ever lose consciousness? □ YES □ NO
- Is your doctor currently prescribing drugs for your blood pressure or heart condition? □ YES □ NO
- Do you have a bone or joint problem that could be worsened by undertaking physical activity? □ YES □ NO
- Do you know of any other reason why you should not undertake physical activity? □ YES □ NO

If you have answered yes to any of the above questions, please talk to your doctor before taking part in this study.

.................................................. (Volunteers signature)
..................................................(Date)
Appendix IV - ISAK Protocol and Definitions

Below are descriptions of the techniques and anatomical sites used to appropriately capture the 39 measurements involved in a full anthropometric profile. All descriptions are taken from Norton et al. (2004) and Marfell-Jones et al. (2006).

Landmarks are identified skeletal points which lie close to the skins surface and can be found by palpating the subject. It is crucial that these landmarks be marked accurately as they underpin the majority of the following measurements. All measurements were taken on the right hand side of the body as standard ISAK procedure dictates.

**Basic Measurements**

1. **Body Mass** – was measured to the nearest 0.1kg using a set of Seca scales (Seca Ltd, Birmingham, UK).

2. **Stretch stature** - participant stands in stocking feet with their head in the Frankfurt plane. Measurer cups the participants jaw in their hands with their fingers on the mastoid processes. The participant takes a deep breath whilst the measurer applies an upwards lift, with measurement taken from the floor to the vertex of the head. Stretch stature was measured to the nearest 0.1cm with a Leicester height measure (Seca Ltd, Birmingham, UK).

3. **Sitting height** – participant sits tall on a box with their head in the Frankfurt plane. Measurer cups the participants jaw in their hands with their fingers on the mastoid processes. The participant takes a deep breath whilst the measurer applies an upwards lift, with measurement taken from the box to the vertex of the head.

**Skinfolds**

All skinfolds were measured using a set of Harpenden 0120 skinfold calipers (Harpenden Ltd, British Indicators, UK) and were taken to the nearest millimetre. Skinfold sites were located via the anatomical landmarks and were marked with a felt pen. The skinfold was grasped between the thumb and index finger with care being taken to avoid including any underlying
tissue. The nearest edge of the skinfold caliper was placed 1cm lateral to the thumb and at $90^\circ$ to the skinfold site. The dial was read after 2 seconds and the reading was recorded. All skinfold measurements were taken twice (and a third time if the first two measurements were not within 5\% of each other) and a mean or median was taken.

4. **Triceps** - this skinfold is vertical and should be parallel to the long axis of the upper arm. The participant should be standing with their arms relaxed and hanging by their sides. The shoulder joint should be slightly externally rotated.

5. **Subscapular** – the participant should be standing with their arms hanging by their sides. This skinfold is raised 2cm along a $45^\circ$ line running laterally and downwards from the under most tip of the scapula.

6. **Biceps** - as for triceps. Site located mid acromiale-radiale.

7. **Iliac Crest** - participant is standing and holds their right arm across their chest. The skinfold is slightly downward posterior to anterior and is directly superior to the iliocristale on the ilio-axilla line.

8. **Supraspinale** - previously known as the suprailiac. Participant should be standing with arms relaxed and hanging by their sides. Skinfold runs obliquely and medially downwards at approximately $45^\circ$ angle. It lies at the intersection between the line from the iliospinale anterior axillary border and the horizontal line of the superior border of the ilium at the level of the iliocristale.

9. **Abdominal** - participant stands with their arms relaxed and hanging by their sides. This measurement should be taken 5cm to the right hand side from the omphalion. The measurer should ensure a firm and broad grasp at this particular site.

10. **Front Thigh** – the participant should sit on the edge of a box, right knee bent at approximately a $90^\circ$ angle and with their foot flat on the floor. This site is parallel to the long axis of the femur and lies mid way between the inguinal fold and the superior border of the patella. The participant was
asked to place both hands under the thigh and lift upwards to relieve tension on the skin thus making the measuring easier.

11. **Medial Calf** – the participant stands on the floor with their right foot on a box (and right knee at approximately a 90° angle). This skinfold is parallel to the long axis of the leg at the most medial aspect of the calf where it is of greatest girth.

**Girths**

Girths were measured using a Rosscraft flexible steel measuring tape (Surrey, Canada) and were measured to the nearest millimetre. The cross hand technique was used with the tape at right angles to the body segment being measured. The tension on the tape was such that there was no indentation made on the skin but the tape was tight enough to hold its place. When reading off the tape, care was taken to ensure that the measurer’s eyes were at the same level as the tape to avoid parallax.

12. **Head** – Ensure long hair is untied to prevent including any hair ties or ponytails in the measurement. Participant sits on a box with their head in the Frankfurt plane. Tape is placed directly above the Glabella, with the tape pulled tight (without indenting the skin) to compress the hair.

13. **Neck** – the participant sits on a box with their head in the Frankfurt plane. Tape placed directly above the thyroid cartilage and perpendicular to the long axis of the neck. Particular care must be taken not to pull the tape too tightly.

14. **Arm Relaxed** – the participant stands with their arms relaxed and hanging by their sides. Right arm should be slightly abducted. Tape should be perpendicular to the long axis of the humerus and the measurement is taken mid acromiale-radiale.

15. **Arm Flexed and Tensed** – the participant stands with their right arm raised anteriorly to the horizontal. The forearm should be supinated and flexed at approximately 45° to the forearm. The measurer gets the tape in place and asks the participant to tense their biceps. The measurement is
taken at the peak of the biceps brachii perpendicular to the long axis of the arm.

16. **Forearm** – the participant stands with their right arm relaxed and supinated. The cross-hand technique is used to find the maximal circumference, which usually occurs immediately distal to the elbow.

17. **Wrist** – the minimum circumference of the wrist distal to the styloid processes. The participant should be standing with the right arm supinated and slightly flexed at the elbow.

18. **Chest** – the participant stands with arms slightly abducted and hanging by their sides. Circumference is taken at the level of the mesosternale, perpendicular to the long axis of the thorax. The participant should be encouraged to breathe normally with the measurement taken at the end of an ordinary expiration.

19. **Waist** – the participant stands with their arms folded across the chest. Measurement is taken at the narrowest point between the lower costal border and the iliac crest, perpendicular to the long axis of the trunk. Again, the participant should be encouraged to breathe normally with the measurement taken at the end of an ordinary expiration.

20. **Gluteal (hip)** – the participant stands with their arms across their chest and feet together. This measurement is taken at the greatest circumference of the buttocks perpendicular to the long axis of the trunk.

21. **Thigh** – the participant stands with their feet slightly apart. Measurement is taken 1 cm below the gluteal fold perpendicular to the long axis of the thigh.

22. **Mid-thigh** – the participant stands with their arms across their chest and feet together. This measurement is taken perpendicular to the long axis of the thigh, midway between the trochanterion and tibiale laterale sites.

23. **Calf** – the participant stands erect on a box. Measurement is taken at the maximal circumference of the calf.
24. **Ankle** – the participant stands on a box. The minimum girth of the ankle is taken superior to the medial malleolus, perpendicular to the long axis of the leg.

**Lengths**

Lengths were measured using a Rosscraft segmometer or a set of large sliding calipers (Rosscraft Campbell Caliper 20) with the latter for measuring foot length only. All measures were taken to the nearest 0.1cm. These instruments are preferable to using a tape measure as they are more rigid therefore give a more accurate reading. Care was taken when taking a measurement that the pointers of the segmometer had not slipped away from the landmark.

25. **Acromiale-radiale** – the participant stands with arms hanging relaxed by their sides, with their right forearm pronated. The linear distance is taken between the Acromiale and Radiale sites.

26. **Radiale-stylion** – the participant stands with arms hanging relaxed by their sides, with their right forearm mid-pronated. The linear distance is taken between the Radiale and Stylion sites.

27. **Midstylion-dactylion** – the participant stands with their right elbow moderately flexed, forearm supinated and with their fingers extended. The linear distance is taken between the Mid-stylion and Dactylion sites.

28. **Iliospinale** – the participant stands with their feet together and their toes under the cut-out section of the box. Measurement is taken from the top of the box to the iliospinale using a segmometer. The height of the box is then added to this measurement to obtain the true measurement.

29. **Trocanterion** – the participant stands with their feet together and the lateral aspect of their right leg towards the box. Measurement is taken from the top of the box to the site of the trocanterion. The height of the box is then added to this measurement.
30. **Trochanterion-Tibiale Laterale** – the participant stands on the box. A segmometer is used to measure the linear distance between the trochanterion and tibiale laterale sites.

31. **Tibiale Laterale** – the participant stands on the box with their feet slightly apart. Distance is measured between the top of the box and the tibiale laterale site, with the segmometer held in the vertical plane.

32. **Tibiale mediale – sphyron tibiale** – the participant sits on the edge of the box with their right leg crossed and right ankle resting on top of the left knee. The linear distance is then taken between the tibiale mediale and the sphyron tibiale sites.

33. **Foot Length** – the participant stands on the box with their weight equally distributed between both feet. The distance is measured between the longest toe and the most posterior point of the heel. This may be either the first or second toe (the latter only in people with Morton’s Toe).

**Breadths**
Breadths were measured using either a large or small set of sliding calipers (Rosscraft Campbell Calipers 20 & 10, Surrey, Canada). All measures were taken to the nearest 0.1cm. Both type of caliper were held in the same way with the caliper lying across the back of the hands with the thumbs on the inside edge of the caliper arms, and the index fingers along the outside of the caliper arms. This allows you to apply appropriate pressure to reduce the thickness of any other tissue, whilst leaving the middle fingers free to locate the bony landmarks.

34. **Biacromial** – the participant assumes a standing position with their arms hanging by their sides. The anthropometrist stands to the rear of the participant. The distance between the lateral aspects of the Acromion processes is measured using a large sliding caliper. The caliper should be held at an upward angle of 45° with firm pressure being applied by the anthropometrist to compress the tissues covering the Acromion processes.

35. **Biiliocristal** – the participant stands on the box with their arms crossed. Again the arms of the caliper are held at an upward angle of
approximately 45° with firm pressure being applied by the anthropometrist. The distance between the most lateral points of the iliac crests is measured.

36. **Transverse Chest** – the participant sits on a box with arms abducted to allow caliper arms to be placed at the lateral border of the ribs. The caliper is positioned at a downwards angle of about 30° and at the level of the Mesosternale. The participant should be encouraged to breathe normally and the measurement is taken at the end of a normal expiration.

37. **Anterior-posterior chest depth** – the participant sits on the box. The large sliding caliper is held horizontally with the front tip of the caliper placed with care on the Mesosternale and the rear caliper placed on the spinous process of the vertebra. Measurement is taken at the end of a normal expiration.

38. **Biepicondylar humerus** - right arm is raised anteriorly to the horizontal. The forearm should be supinated and flexed at approximately 45° to the forearm. The linear distance between the medial and lateral epicondyles is measured.

39. **Biepicondylar femur** - the participant sits on the box with their right foot on the floor and the knee bent at a right angle. The middle fingers should be used to palpate for the epicondyles. The caliper faces are placed on the most lateral and medial epicondyles with firm pressure applied until the measurement is taken.
Appendix V - Equations

The following equations were used to gain additional information from the 39 ISAK measurements.

**Corrected Girths**
To calculate corrected thigh girth, corrected forearm girth, corrected waist girth and corrected calf girth the following equation was used:

\[ \text{CG} = \text{G} - (0.314 \times \text{sf}) \]  
\[ \text{Martin et al (1990)} \]

Where
- \( \text{CG} \) = corrected girth
- \( \text{G} \) = measured girth
- \( \text{sf} \) = measured skinfold at that site

To calculate the corrected forearm girth the biceps skinfold was used as there is no skinfold measurement taken from the forearm.

**Muscle Mass**
To calculate muscle mass the following equation was used:

\[ \text{MM (g)} = \text{stature} \times (0.0553 \times \text{CTG}^2 + 0.0987 \times \text{FG}^2 + 0.0331 \times \text{CCG}^2) - 2445 \]  
\[ \text{(Drinkwater et al, 1986)} \]

Where
- \( \text{stature} \) = stretch stature in centimetres
- \( \text{CTG} \) = corrected thigh girth
- \( \text{FG} \) = uncorrected forearm girth
- \( \text{CCG} \) = corrected calf girth

**Fat Free Mass (Males)**
To calculate FFM in the male participants the following equation was used:

\[ \text{FFM (g)} = 689m + 285SH + 1025CFG + 534CCG - 473CWG - 20895 \]  
\[ \text{(Stewart & Hannan, 2000)} \]

Where
- \( m \) = body mass in kilograms
SH = sitting height in centimetres
CFG = corrected forearm girth
CCG = corrected calf girth
CWG = corrected waist girth

**Fat Free Mass (Females)**
To calculate FFM in the female participants the following equation was used:

\[
FFM = 1.0994921 - (0.0009929 \text{ SUM}) + (0.0000023 \text{ SUM}^2) - (0.0001392 \text{ AGE})
\]

Where SUM= sum of triceps, abdominal and front thigh skinfolds
Age is in years
(Jackson *et al.*, 1980)

**Arm Spread**
Arm spread was calculated by the addition of one measured breadth and 3 measured lengths, though it was found that this tended to give a larger value than the participants normal arm span

\[
\text{Arm spread} = \text{biacromial breadth} + 2(\text{acromiale-radiale}) + 2(\text{radiale-styliion}) + 2(\text{midstyliion-dactylion})
\]
Appendix VI – Somatotype Equations

Somatotype is defined using the following equations:

**endomorphy** = -0.7182 + 0.1451 x ΣSF - 0.00068 x ΣSF^2 + 0.0000014 x ΣSF^3
where ΣSF = (sum of triceps, subscapular and supraspinale skinfolds) multiplied by (170.18/height in cm)

**mesomorphy** = 0.858 x humerus breadth + 0.601 x femur breadth + 0.188 x corrected arm girth + 0.161 x corrected calf girth - height x 0.131 +4.5

There are 3 different equations used to calculate the ectomorphy rating according to the participant’s height to weight ratio (HWR).

HWR = Height (cm) / \(\frac{3}{2}\)√weight (kg)

If HWR ≥ 40.75 then:

**ectomorphy** = 0.732 x HWR - 28.58

If HWR < 40.75 and >38.25 then:

**ectomorphy** = 0.463 x HWR - 17.63

If HWR ≤ 38.25 then:

**ectomorphy** = 0.1

The participant’s somatotypes were all calculated on the ISAK spread sheet; however the author calculated 2 of these by hand to check for correctness.
**Participant 5 (female)**

\[ \Sigma SF = (13.7 + 7.6 + 6.9) \left( \frac{170.18}{172.0} \right) \]

= 27.9

\[ \text{HWR} = \frac{172}{\sqrt[3]{59.7}} \]

= 44.0

Endomorphy = \(-0.7182 + 0.1451 \times 27.9 - 0.00068 \times 27.9^2 \)
\[ + 0.0000014 \times 27.9^3 \]

= 2.8

Mesomorphy = 0.858 \times 6.2 + 0.601 \times 9.0 + 0.188 \times 24.4 + 0.161 \times 33.0 - 172 \times 0.131 + 4.5

= 2.6

Ectomorphy = 0.732 \times 44.0 - 28.58

= 3.6

**Participant 40 (male)**

\[ \Sigma SF = (10.4 + 11.1 + 5.7) \left( \frac{170.18}{188.9} \right) \]

= 24.5

\[ \text{HWR} = \frac{188.9}{\sqrt[3]{79.7}} \]

= 43.9

Endomorphy = \(-0.7182 + 0.1451 \times 24.5 - 0.00068 \times 24.5^2 \)
\[ + 0.0000014 \times 24.5^3 \]

= 2.4

Mesomorphy = 0.858 \times 6.9 + 0.601 \times 9.8 + 0.188 \times 29.6 + 0.161 \times 37 - 188.9 \times 0.131 + 4.5

= 3.1

Ectomorphy = 0.732 \times 43.9 - 28.58

= 3.6
Please find enclosed your anthropometric profile. Thank you very much for your time and cooperation in taking part in my study. Here is a small explanation of some of the numbers and some reference values that may be of interest to you:

**Phantom Z Value** – “The Phantom is a unisex reference human designed as a proportionality computation device, not a norm. Derived from the literature and internal constraints, the Phantom serves as a calculation device to obtain proportionality scores (z-values) that are used to compare individual or group proportionality characteristics” (Ross, 2000). In plain English, all of your results have been looked at in relation to your height. The z-scores are a measure of your proportionality. For example, if your z-score is 0 for sitting height then you are exactly in proportion for this measure. If it is a minus number, your sitting height is shorter than expected and if it is a plus number your sitting height is taller than expected. Elite rowers have been found to have proportionally longer legs (iliospinale height), therefore a shorter sitting height, proportionally lower skinfold readings and proportionally narrower hips (gluteal girth).

**Somatotype** is a classification of body type based on the prominence of different tissue types. An absolute endomorph would look like a sumo wrestler, an absolute mesomorph would be a person short in stature with a large muscle mass and an absolute ectomorph would be long and lean, for example a high jumper. You are given a 3 number score, each from 1 – 7 with 1 being low and 7 being high.

**Body Mass Index** = \( \frac{\text{weight (kg)}}{[\text{height (m)}]^2} \)

Recommended BMI for healthy adults is 18.5 – 24.9. However, care should be taken when interpreting your results as accuracy is distorted by muscle mass and BMI can only really be used to broadly categorise people. A person with a large muscle mass can easily be placed in the ‘overweight’ or ‘obese’ category even if they have a very low body fat purely because they are heavy for their height.
**Waist to hip ratio** has been shown to correlate well with health and a high WHR is one risk factor in heart disease. To be in the low risk category a male should have a WHR of less than 0.95 and a female less than 0.8.

Here are some reference values for **% body fat**. They are a bit ambiguous – what do they mean by athletes and fitness? Please use it only as a general guide.

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>Essential Fat</td>
<td>10 – 13%</td>
<td>2 – 5%</td>
</tr>
<tr>
<td>Athletes</td>
<td>14 – 20%</td>
<td>6 – 13%</td>
</tr>
<tr>
<td>Fitness</td>
<td>21 – 24%</td>
<td>14 – 17%</td>
</tr>
<tr>
<td>Acceptable</td>
<td>25 – 31%</td>
<td>18 – 25%</td>
</tr>
</tbody>
</table>

**Sum of 8 skinfolds** - simply the sum of the 8 skinfold measurements that I took. It is actually much better to use this as a measure of adiposity than % body fat. To work out your % body fat your skinfold measurements go through an equation that has a degree of error in it. Therefore it is much better to leave your body fat measurement as the sum of skinfolds and to compare this to any previous or future readings.

If you would like to be measured later in the season for your own interest please let me know. Many thanks again for taking part and I will let you know once I have any more findings.