BIOMECHANICAL AND PHYSIOLOGICAL DETERMINANTS OF 2000 M ROWING PERFORMANCE ON SLIDES ERGOMETER

By

MUHAMMAD IRWAN BIN ABDULLAH

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ABSTRAK

Fisiologi merupakan faktor penting yang menentukan prestasi dalam sukan mendayung yang mampu membezakan walau satu saat antara pemenang dengan peserta lain. Namun begitu peranan biomekanik dan teknik dalam menggunakan tahap fisiologi secara efektif juga sangat penting. Peranan faktor fisiologi dan biomekanik terhadap prestasi sukan mendayung telah dikaji selidik secara meluas oleh penyelidik-penyelidik sebelum ini. Namun, tiada kajian yang menggabungkan faktor fisiologi dan biomekanik dalam menentukan prestasi sukan mendayung. Tujuan kajian ini adalah untuk mengkaji penentu biomekanikal dan fisiologi dalam ujian masa mendayung 2000 m menggunakan '*slides ergometer*'. 10 orang pendayung negeri Terengganu terpilih mengikuti kajian ini. Tiga ujian fisiologi dijalankan bagi mengumpul data aerobik, anaerobik, antropometri, biomekanikal dan juga keputusan ujian masa mendayung 2000 m. Ujian korelasi Pearson digunakan untuk menentukan perkaitan antara pembolehubah ini dengan masa ujian mendayung 2000 m. Keputusan kajian menunjukkan wujud perkaitan antara aerobik, anaerobik dan biomekanikal dengan masa ujian mendayung 2000 m. *Peak power* (P_{peak}) ($r = -0.937$) dan sudut lutut pada kedudukan *catch* pada jarak 1200 m ($r = 0.888$) adalah penentu utama prestasi mendayung ergometer, diikuti dengan sudut lutut pada kedudukan *finish*, sudut pinggang pada kedudukan *catch*, peratusan lemak badan, sudut pinggang pada kedudukan *finish*, tinggi badan, lactate selepas ujian dan VO_2. Keputusan ujian boleh digunakan untuk merencana latihan dan juga pemilihan pemain. Lebih banyak masa perlu digunakan untuk meningkatkan kekuatan otot. Kekuatan dan keseimbangan otot-otot sekitar pinggang dan lutut mampu meningkatkan prestasi persembahan pendayung malah berkemungkinan mampu mengurangkan kadar kecederaan otot.

ABSTRACT

Physiology is believed to be the most important determinant in rowing performance that can help rowers win or lose tens of seconds in a race. However, there is also the role of biomechanics and rowing technique to apply the rower's present physiological fitness level most effectively. The effects of physiological and biomechanical factors on rowing performance have been tested in many previous studies but currently there is no study that combines the physiological and biomechanical factors in determining rowing performance. The purpose of this study was to investigate the biomechanical and physiological determinants of 2km rowing performance on slides ergometer. Ten state-level rowers were recruited to participate in this study. Three tests were completed to gather the data on aerobic, anaerobic, anthropometry and biomechanical variables and also 2000 m rowing performance time. Pearson's correlation test was used to determine correlation of these with 2000 m time. Result showed that aerobic capacity, anaerobic capacity and biomechanical variables were correlated with 2000 m time. Peak power ($r = -0.937$) and knee angle at catch at 1200 m ($r = 0.888$) were the major determinants of ergometer rowing performance, followed by knee angle at finish at 2000 m ($r = -0.872$), hip angle at catch at 2000 m ($r = 0.85$), body fat percentage ($r = 0.828$), hip angle at finish at 800 m ($r = -0.807$), body height, post-test lactate and oxygen uptake (VO_2). The findings could be use for training design and recruitment. More time should be allocate to improve muscle power. Increase in strength and balance on muscles around hip and knee areas, particularly the hip and knee flexors may increase performance and also possibly prevent muscle injury.

1. INTRODUCTION

1.1. BACKGROUND OF STUDY

Rowing is a strength-endurance type of sport where performance depends on many factors such as physiology, biomechanics, anthropology, psychology, rowing technique and tactics. As a highly ranked endurance sport, rowing require a large aerobic capacity to maintain the high intensity of rowing performance. A research by Cosgrove *et al.*, (1999) found that maximal oxygen uptake (VO_{2max}) showed the highest correlation with the velocity for the 2000m time-trial and is the best single predictor of rowing performance. These findings are consistent with another study by Russell *et al.*, (1998) which found that, VO_{2max} was correlated with their 2000m performance time whereas accumulated oxygen deficit (AOD) did not. These findings suggest that rowing performance is dependent upon the functional capacity of aerobic energy pathway but not on anaerobic energy pathway. Another research by Pripstein and colleagues (1999) proved otherwise. This study found a correlation between anaerobic capacity by means of AOD_{max} and 2000m performance race time. They observed that high anaerobic capability improved rowing performance even though anaerobic energy sources contributed only 12% of total energy during rowing performance in this study.

Several studies included kinematics in their research. McGregor *et al.*, (2004) investigated the impact of different rowing intensities on rowing technique, force generated during rowing stroke and kinematics of spinal motion during rowing stroke cycle. They observed the change in sagittal plane spinal kinematics with increasing rowing intensity, and related this to the development of low-back pain and acute injury. They also noted that rowing kinematic and force profiles changed at higher rowing intensity. These changes may be an important factor related to injury mechanism. On the other hand, Hofmijster and colleagues (2008) investigated the effects of technical skill on rowing stroke power and efficiency by taking into account various force profiles, aerobic capacity and body kinematics. The kinematic measures however were only measured as trajectory for the whole body centre of mass. They came out with suggestion that in order to effectively transfer the forces from the feet to the hands, an athlete should aim to maintain a good spinal posture through a stiff connection from hips. Velocity efficiency also improves by keeping the speed of the rower's centre of mass in the recovery phase to a minimum. From these studies, the importance of biomechanical analysis during rowing was emphasized.

Rowing ergometers are designed to simulate the movements performed during rowing on-water. Most of rowing race-training were completed on-water, however rowing ergometers are still commonly used for performance testing, technique coaching, crew selection or for training during poor weather (Soper and Hume, 2004). Traditional ergometers are stationary where the rower moves according to the resistance unit of the machine. To better simulate on-water rowing, dynamic ergometers, an improvisation from the stationary ergometer was invented (Shaharudin *et al.*, 2014). In dynamic ergometer, parts or all of the ergometer moves in response to the motion of the athlete.

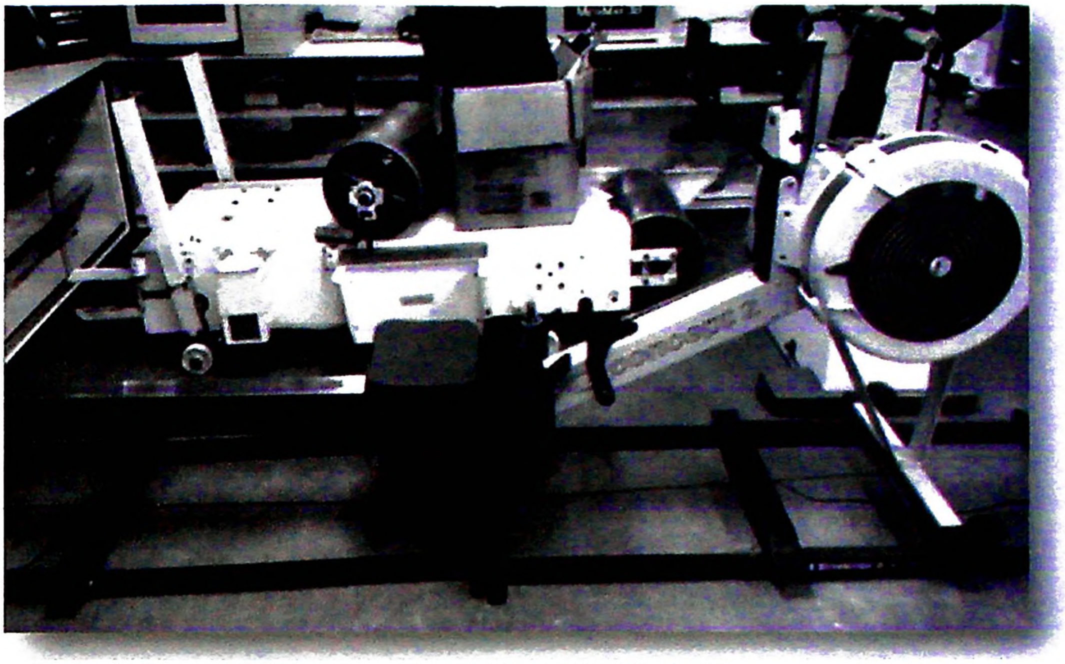

Figure 1 : Concept 2 slides ergometer which used in this study.

There are three types of rowing ergometer used in previous study in our review which are RowPerfect, Concept 2 and WaterRower. Slide ergometer of Concept 2 model E ergometer (Morrisville, USA) was the most commonly used and considered accurate and repeatable (Steer *et al.*, 2006), better for injury prevention

was able to help rowers feel for the water more than

Benson *et al.*, 2011). Despite its wide usage, currently

aluate the relationship of anthropometric, physiological

in determining the outcomes of rowing performance,

ıe trial test.

1.2. PROBLEM STATEMENT

Physiology is believed to be the most important determinant in rowing performance that can help rowers to win or lose tens of seconds in a race. However, there is also role of biomechanics and rowing technique to apply the rower's present physiological fitness level most effectively. Coaches are spending most of their time on the effective technique training but there are no guidelines on what is the most suitable rowing technique. They are challenged to find and determine a technique and the movement pattern that best fits all rowers within the capacity of their skill and level.

The effects of physiological and biomechanical factors on rowing performance have been tested in many previous studies. However, to the best of our knowledge, currently there is no study that combines the physiological and biomechanical factors in determining rowing performance. It is important to determine the physiological determinants of rowing performance in addition to finding the right and effective technique based on the rower's present physiological fitness level. This study is designed to investigate rowing performance determinants by the inclusion of physiological and anthropometric variables in addition to kinematic profiles during rowing on slides ergometer.

1.3. PURPOSES OF STUDY

The main focus of the study is the kinematics of rowing that determines the effective rowing technique. Moreover, anthropometric and physiological factors also play important roles that affect rowing performance. Therefore, the purpose of this study is to investigate the kinematics and physiological determinants of 2km rowing performance on slides ergometer.

1.4. OBJECTIVES

General objective : To investigate the physiological and biomechanical factor of rowing performance on slides ergometer.

Specific objectives :

1. To investigate the effects of aerobic capacity on 2km rowing performance on slides ergometer.
2. To investigate the effects of anaerobic capacity on 2km rowing performance on slides ergometer.
3. To investigate the effects of biomechanical aspects on 2km rowing performance on slides ergometer.

1.5. RESEARCH QUESTIONS AND HYPOTHESES

Question 1: Does aerobic capacity relate to 2km rowing performance on slides ergometer?

H_o = Aerobic capacity is not related to 2km rowing performance on slides ergometer.

H_1 = Aerobic capacity is related to 2km rowing performance on slides ergometer.

Question 2: Does anaerobic capacity relate to 2km rowing on slides ergometer performance?

H_o = Anaerobic capacity is not related to 2km rowing performance on slides ergometer.

H_1 = Anaerobic capacity is related to 2km rowing performance on slides ergometer.

Question 3: Does biomechanical aspects of rowing relate to 2km rowing on slides ergometer performance?

H_o = Biomechanical aspects of rowing is not related to 2km rowing performance on slides ergometer.

H_1 = Biomechanical aspects of rowing is related to 2km rowing performance on slides ergometer.

1.6. SIGNIFICANCE OF THE STUDY

As an intense sport, rowing requires high demand of both anaerobic and aerobic pathways. Moreover, there are four phases of movement in rowing skills that define the kinematics of rowing. Hence, detailed inspection on rowing kinematics during specific physiological tests may help in determining the right and effective rowing stroke technique across various physiological demands. Therefore, this study is designed to develop a methodology to specifically focus on the rowing kinematics in different energy demands. Relating physiological and biomechanical variables to performance could be valuable for designing training programs and for team selections.

2 : LITERATURE REVIEW

2.1 PHYSIOLOGY OF ROWING

Rowing is a strength-endurance type of sport where performance depends on many factors such as physiology, biomechanics, anthropology, psychology, rowing technique and tactics. Many researches have tried to define performance parameters in rowing. Different levels of rowers and boats were utilised and different performance parameters were frequently tested in these studies. Most of the studies focused on physiological parameters such as maximal oxygen uptake (Cosgrove *et al.*, 1999; Russell *et al.*, 1998; Pripstein *et al.*, 1999), peak power output (Bourdin *et al.*, 2004), power at VO_{2max} (Ingham *et al.*, 2002), maximal muscle strength (Izquierdo-Gabarren *et al.*, 2010) and body mass (Russell *et al.*, 1998; Barrett and Manning, 2004; Izquierdo-Gabarren *et al.*, 2010).

Many studies reported strong relationship between rowing performance and aerobic capacity (Cosgrove *et al.*, 1999; Russel *et al.*, 1998). As a highly ranked endurance sport, rowing requires a large aerobic capacity to maintain the high intensity of rowing performance. A research by Cosgrove et al. (1999) examine the relationship between selected physiological variables of rowers and rowing performance among 13 male club standard rowers. They found that maximal oxygen uptake (VO_{2max}) showed the highest correlation with the velocity for the 2000m time-trial and is the best single predictor of rowing performance. Rowers and coaches could apply these findings in designing training programmes by spending more time to improve their VO_{2max}. These findings are consistent with another study by Russel *et al.* (1998) who observed that VO_{2max} was correlated with 2000m performance time among 19 elite schoolboy rowers whereas AOD did not. These results suggested that rowing performance is dependent upon the functional capacity of aerobic energy pathway but not on anaerobic energy pathway. There were critics that the results that be influenced by stage of training when the test was conducted, which was at the beginning of pre-competition when there were little anaerobic training. Another research by Pripstein *et al.* (1999) proved otherwise. This study found a correlation between anaerobic capacity by means of AOD_{max} and 2000m performance race time. They indicated that high anaerobic capability improved rowing performance eventhough anaerobic energy sources contributed only 12% of total energy during rowing performance in this study. It was noted that, during rowing, 70% to 87% of energy was derived from aerobic metabolism while only 12% to 30% of energy was contributed by anaerobic metabolism (Russel *et al.*, 1998; Pripstein *et al.*, 1999).

Muscle power output and muscle maximal strength are other important aspects in rowing. There were studies that tried to emphasise the important factors of these aspects (Izquierdo-Gabarren *et al.*, 2010; Bourdin *et al.*, 2004). Elite rowers had higher absolute values of maximal strength, muscle power-load curve and maximal number of repetitions until failure with 75% of 1-Repetition Maximum (1-RM) during bench-pull (Izquierdo-Gabarren *et al*, 2010). Izquierdo *et al.* (2010) compared the best prediction factors of traditional rowing performance between elite (ER) and amateur (AR) rowers and they found that maximal muscle strength during bench-pull action was 13% higher in ER than in AR. The average power output index was 6–13% higher in ER than in AR. These differences between ER and AR in power and strength may indicate that high absolute values of maximal strength and muscle power are required for successful performance in traditional rowing. However, this study only tested on strength of upper extremity muscles which is mostly used in traditional rowing. To our knowledge, there is no study on the contribution of lower extremity muscles strength to rowing performance. Another research by Bourdin et al. (2004) aimed to test the hypothesis that peak power output (P_{peak}) sustained during maximal incremental testing among 54 highly trained rowers would be an overall index of rowing ergometer performance over 2000 metres. Results showed that P_{peak} was the best predictor of rowing ergometer performance. Ingham et al. (2002) suggested that maximal force (F_{max}), power at VO_{2max} (W_{VO2max}) and maximal power (Wmax) production were the strongest correlates to rowing performance. (Ingham *et al.*, 2002) also demonstrated different result between heavyweight rowers and lightweight rowers. This lead to another important determinant of rowing performance, which is anthropometric profiles.

International elite rowers tend to be tall with high lean mass and aerobic power (Cosgrove *et al.*, 1999). Rowers with more lean body mass have larger muscle mass than rowers with less lean body mass suggesting that rowers with higher lean body mass are potentially able to produce greater force during the stroke. Cosgrove *et al.* (1999) suggested to the rowers of lightweight category (<72.5 kg) to try to gain their lean body mass by reducing their body fat to allow them to maximise their muscle mass while staying within their weight category. Another study by Barret & Manning (2004) tried to find the relationship between anthropometry measures including height, sitting-height, arm span, thigh length, knee to floor length, leg length, arm girth, hip girth, body mass and body mass index (BMI), with rowing performance. They found the most important determinants of rowing performance were body mass, height, strength and ergometer time, which concluded that the best rowers are larger, heavier and stronger compared to their teammates. Russell *et al.*, (1998) measure height, body mass and skinfold in their study and found that there were high correlation between these anthropometric variables with 2000m rowing time. Russel *et al.* (1998) related this finding with the relationship between morphology with human performance, which was in parallel to Carter (1985) who observed that morphology was related to both the physiology and biomechanics of humans in motion.

2.2 KINEMATIC OF ROWING

Physiology was believed to be the most important determinant in rowing performance which can help rowers to win or lose tens of seconds in a race. However, there is a role of biomechanics and rowing technique to utilise the rower's present physiological fitness level more effectively. Coaches spend most of the time on the effective technique training but there are no guidelines on what is the most suitable rowing technique. The coach is challenged to find and determine a technique and the movement pattern that best fits all rowers given their skill and level. Hence, insights regarding rowing biomechanics across different physiological demands are crucial.

Rowing is a cyclic, repetitive movement that can be separated into two different phases, drive and recovery (Figure 2.1). The drive phase starts at the catch position (full flexion of the lower limb and lumbar joints and full extension of the upper limb joints) and ends at the finish position (full extension of the lower limb and lumbar joints and full flexion of the upper limb joints). The drive phase involves muscular actions to flex the elbow and shoulder joints and to extend the ankle, knee, hip and lumbar joints. In other words, the rower slides backward on the rolling seat by extending knee and ankle joints. With the blades in the water, the rower is pulling the oar. The recovery phase is when the rower returned to the catch position from the finish position of the following cycle. The rower slides forward by flexing the knee and ankle joints. The oars are lifted out of the water during this phase. As a conclusion, rowing stroke action is a complex activity that needs coordination between the trunk, upper and lower limb muscles (Colloud *et al.*, 2006).

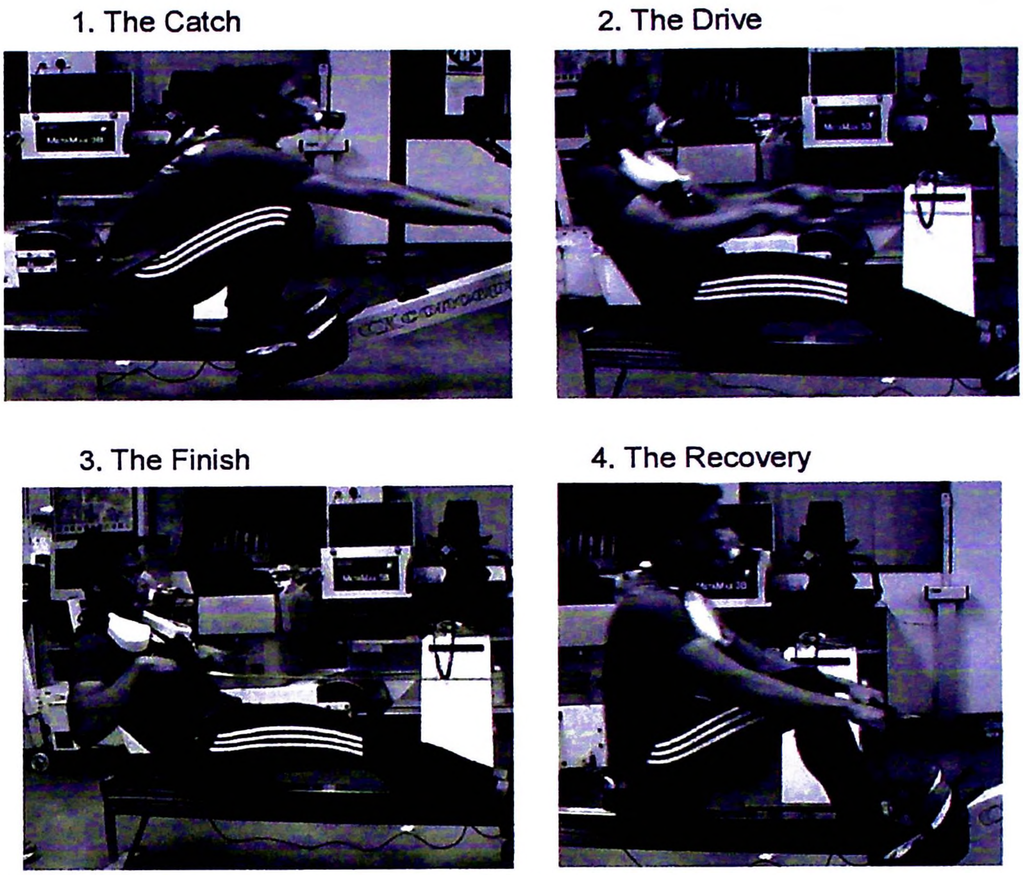

Figure 2.1 : Phases of rowing. Start from the catch, drive, finish and recovery.

Stroke rate is an important aspect of rowing technique and is changing during a 2000-m race (Hofmijster *et al.*, 2007). Stroke rate is typically highest during the first and last 250 m. Changing the stroke rate is likely to have an effect on the mechanical power in rowing. With increasing stroke rate, rower's average net mechanical power output of a single cycle is increased. Accelerations of the rower are expected to be greater at higher stroke rates, which will increase boat velocity due to more impulse exchanges between rowers and boat (Hofmijster *et al.*, 2007). Černe *et al.*, (2013) studied the dependency of technique on stroke rate. Their results showed that elite rowers used similar and consistent technique at all stroke rates. This study also relate stroke rate with stroke length. The pattern of stroke length in elite rowers was consistent through different stroke rate, whereas in non-rowers, stroke length was shorter than elite rowers and increased with increase stroke rate. Shorter stroke length in non-rowers was because of consequence of smaller trunk inclination and knee flexion at the starting of the drive and shortening of the stroke at finishing of the drive phase which was due to poor handle pulling technique (Cerne *et al.*, 2013).

Many studies tried to investigate body movement during rowing stroke using different parameters. In formulating the effective rowing technique, the first important thing is to understand the stroke cycle including the movement patterns and the underlying forces. In other words, stroke cycle comprises of kinematics and kinetics that determines the outcomes of rowing stroke. Manipulating the overall movement style produces more powerful and efficient stroke cycle, which then produces a good rowing stroke cycle (Soper and Hume, 2004). Many researchers have previously studied the joints and segments motion during different phases of stroke cycle. Colloud *et al.* (2006) measured the force and handle displacement, and they demonstrated ways in which not only able to analyse performance variables but also technical issues related to different ergometer setups, injury and fatigue. This study concluded that with different stretcher mechanisms, muscular coordination may differ and the slide ergometer mechanism may induce lower catch and maximum values for net joint forces and net joint moments that could decrease the risk of injury. Even though this study have shown benefits in limited biomechanical analysis, there was one important thing they did not consider in their study, which is the kinematics of rowers, the way the rowers move to produce the parameters that they measured.

Several studies included kinematics in their research. McGregor *et al.* (2004) investigated the impact of different rowing intensities in relation to rowing technique, the force generated during the rowing stroke and the kinematics of spinal motion during rowing stroke cycle. They observed changes in sagittal plane spinal kinematics with increasing exercise intensity, and relating this to the development of low-back pain and acute injury. Results showed that rowing kinematic and force profiles changed at higher rowing intensities. These changes may be an important factor related to injury mechanism. Hofmijster *et al.* (2008) investigated the effects of technical skill on rowing stroke power and efficiency by taking into account various force profiles, aerobic capacity and body kinematics. The kinematic measures however were only measured as a trajectory for the whole body centre of mass. They came out with suggestion that in order to effectively transfer force from feet to hands, a rower should aim to maintain a good spinal posture through a stiff connection at the hip. They also noted that the movement efficiency also improved by keeping the speed of the rower's centre of mass in the recovery phase to a minimum.

Caldwell *et al.*, (2003) investigated the effects of repetitive motion. Muscle activity and lumbar flexion were analysed in subjects whilst performing a rowing trial on an ergometer. They noted the adverse effect that fatigue can have on maintaining good technique. The findings showed that during the drive phase of rowing stroke, rowers obtained relatively high levels of lumbar flexion that increased across the duration of the trial. Results also showed evidence that muscle fatigue occurred, and may be responsible for the increased levels of lumbar flexion over the rowing trial. An awareness of increased lumbar flexion and muscle fatigue in the erector spinae muscles during rowing may be an important consideration for injury prevention programs for rowers. Furthermore, O'Sullivan *et al.* (2003) measured the lumbar spinal and pelvic motion using an electromagnetic measurement device while rowing on an ergometer using normal technique, three common bad technique variants, and after a

10 minute session of rowing to simulate fatigue. This research had shown the possibility to record accurately the movement of the lumbosacral spine and the thoracolumbar spine using an electromagnetic motion tracking system and may give useful information on the motion of the body parts during rowing stroke cycle. Results showed significant difference between the different rowing techniques for femoral, thoracolumbar and lumbosacral flexion. They concluded that kinematic parameters of spinal motion of rowers can be measured dynamically and then can be used to determine the difference between efficient and less efficient rowing styles.

Many people who use rowing ergometers are getting little or no instruction in rowing technique in a safe and correct way. Ergometer training is a common cause of back pain and injury in competitive rowers but there were no evidence of similar risk of musculoskeletal problems among non-rowers who used ergometer rowing regularly (Hase *et al.*, 2004). Hase *et al.* (2004) examined injury prediction when studying the kinematics and kinetics of a rowing stroke cycle. The objective of their study was to assess the differences in kinematics, kinetics and musculoskeletal loading of competitive experienced rowers and non-experienced rowers during rowing performance. Kinematic, external force and electromyography (EMG) data were collected among five university-level competitive rowers and five non-experienced rowers. Their findings demonstrated that the experienced rowing group displayed higher contact forces at the knee and higher peak lumbar and knee flexion moments. The competitive experienced rowers generated higher model quadriceps muscle forces and pushed harder against the foot cradle, more extension of the knee and less on their trunk compared to the non-experienced rowers group during the drive phase. The competitive rowers group also showed higher contact forces at the knee and higher peak lumbar and knee flexion moments in order to slow themselves down at the end of the drive phase before changing direction for the recovery phase. These results gave room for predicting the potential risk of injury during rowing.

2.3 ROWING ERGOMETER

Rowing ergometers were designed to simulate the movements performed during rowing on-water. Most of rowing race training is completed on-water, however rowing ergometers are still commonly used for performance testing, technique coaching, crew selection or for training during poor weather (Soper and Hume, 2004). Traditional ergometers are stationary where the rower moves according to the resistance unit of the machine. To better simulate on-water rowing, dynamic ergometers, an improvisation from the stationary ergometer was invented (Shaharudin *et al.*, 2014). In dynamic ergometer, parts or all of the ergometer moves in response to the motion of the athlete (Figure 2.2).

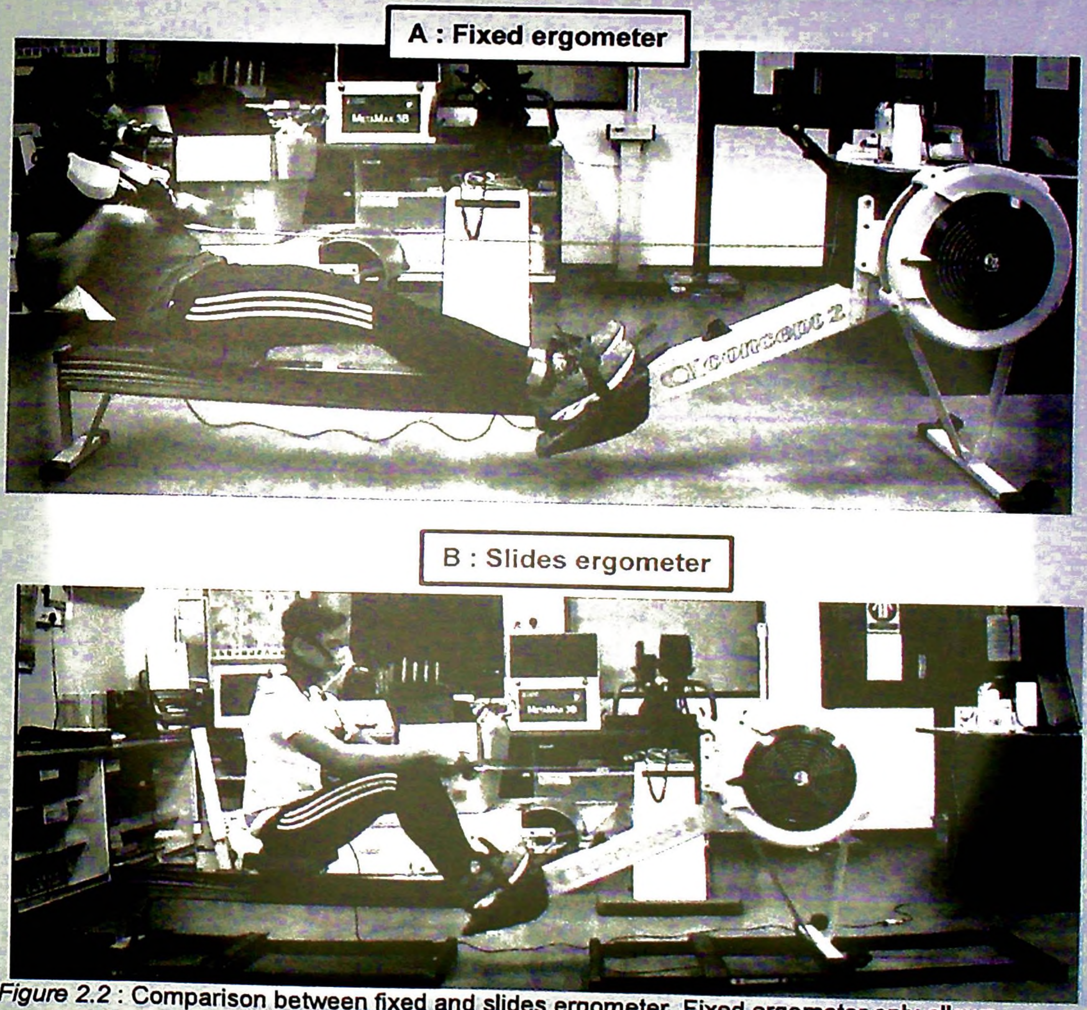

Figure 2.2 : Comparison between fixed and slides ergometer. Fixed ergometer only allows movement of the rower, whereas in slides ergometer all parts of the ergometer moves in response to the movement of the rower.

There are three types of rowing ergometer used in a previous study which were RowPerfect, Concept 2 and WaterRower. RowPerfect ergometer's ability to simulate rowing performance on water is physiologically reliable (Elliott *et al.*, 2002). Elliot *et al.* (2002) attempted to compare rowing stroke technique between dynamic RowPerfect ergometer with an on-water single scull. Four male and four female national junior level rowers performed on both the ergometer and in the single scull for over 500m at different rates. The force curve produced from the RowPerfect ergometer was similar in shape to that of single scull rowing. The five sequential normalised force curves for the right and left hands were similar. There was no significant different in body positions at the catch and finish between performance on RowPerfect ergometer and on water. Elliot *et al.* (2002) stated that it is necessary for specific training or even crew selection to be done on an ergometer that has a rowing structure as similar as to on-water rowing as possible.

Study by Steer *et al.* (2006) compared the kinematics of lumbopelvic region during rowing between fixed-head design of two rowing ergometer, the Concept 2 ergometer and WaterRower. WaterRower was designed in which a mass of water is moved rather than air. This type of rowing ergometer is able to maintain a constant resistance through the stroke in order to more realistically represent the on-water condition. The kinematics of lumbo-pelvic region of twelve novice male rowers on those two different ergometer were assessed. They concluded that rowing kinematics on the Concept 2 ergometer was considered more accurate and repeatable than rowing kinematics on WaterRower. There are differences in technique between different ergometer designs but it was suggested by this study that the WaterRower can cause a wrong technique. Further investigation is required to confirm this.

There were many studies that compared between fixed and slides ergometer. Most of them used Concept 2 ergometer for both designs. Only one research in literature review utilised RowPerfect to compare the rowing performance in fixed and slides ergometer. Colloud *et al.* (2006) investigated mechanical response on traditional fixed stretcher ergometer and free-floating ergometer of RowPerfect. The results suggested different muscular coordination were activated during rowing on fixed and slides ergometer.

Studies that compared different mechanism between dynamic and stationary rowing ergometer using Concept 2 ergometer dominates the literature review (Benson *et al.*, 2011; Mello *et al.*, 2014; Shaharudin & Agrawal, 2015). Benson *et al.* (2011) compared the biomechanical and physiological responses between dynamic and stationary Concept 2 ergometer. Elite rowers have higher stroke rates and lower stroke force on dynamic ergometer. These may cause a higher demand on cardiopulmonary system and reduced force production in new rowers. Dynamic ergometer can help rowers to feel for the water with close resemblance of force profiles similar to rowing on water while able to maintain high stroke rates. Furthermore, Benson *et al.* (2011) and Holsgaard-Larsen and Jensen, (2010) found lower biomechanical load while rowing on dynamic ergometer compared to stationary ergometer. It was believed that stationary ergometer was able to improve force production during rowing, although both ergometers are equally useful for cardiopulmonary fitness training. As training tool, dynamic ergometer is just as demanding as stationary ergometer with regards to utilisation of aerobic energy sources and even higher utilisation for anaerobic sources. This statement is conflicting with study by Mello *et al.* (2014) who noted that dynamic ergometer provide more specificity to physiological test compared to stationary design. However, the findings of the study were not conclusive due to limited number of subjects (n = 8).

Based on the literature reviewed, we were provided with useful insights into the various aspects of rowing performance. However, there has been no study that had conducted a comprehensive study on kinematics of rowing performance. Most of the studies have room for improvement in their methodology or the reliability of their measurements. Most studies on biomechanical aspects in rowing included kinematics in their study but with some limitations. Colloud *et al.* (2006) investigated mechanical aspect of rowing but not included kinematics variables in their research. Study by Hase *et al.* (2004) used low number of subjects (five rowers and five nonrowers), and only two rowing strokes were recorded and used to represent an individual's technique. Some other studies have limited variables and only assessed certain part of body kinematics. For example, study by Caldwell *et al.* (2003) investigated kinematical changes in lumbar flexion that is highly similar to the study by O'Sullivan *et al.* (2003) that focused on the kinematic of the spine bone. Hence, these are the gaps in the literature which this present study aims to address.

Some coaches are limited only to one aspect of measurement. For example, coaches that only measure the anthropometric variables of their rowers, and therefore would base their predictions of their rowers' performance solely on the anthropometric measurements. They decided to determine the impact of individual sets of variables due to practical implications. A combination of selected anthropometric and physiological variables are better predictors of rowing ergometer performance in rowers than either category of variables or individual variables alone (Mikulić and Ružić, 2008). So, we decided to include physiological and anthropometric variables in our study in addition to kinematic profiles. Slide ergometer of Concept 2 model E (Morrisville, USA) is commonly used and recommended by many studies in our review due to its accuracy and repeatability (Steer *et al.*, 2006), better for injury prevention (Colloud *et al.*, 2006) and assist rowers to feel for water movement more than any other rowing ergometer (Benson *et al.*, 2011). Thus, we chose Concept 2 as the ergometer to be used in the present study.

3 : METHODOLOGY

3.1 EXPERIMENTAL DESIGN

The study was a cross-sectional study. Data collection was conducted at Majlis Sukan Negeri (MSN) Terengganu. Two visits were required to finish all the data collection sessions among the participants.

3.2 PARTICIPANTS

Ten state level rowers (6 male; 4 female) participated in this study. The participants were recruited from Terengganu state rowing team. All participants have at least two years of training in competitive rowing. All rowers are physically healthy without any musculoskeletal injuries within the last two years. For each subject, all methods and procedures were thoroughly informed and a written informed consent was obtained before participating in this study. All tests and scientific experiments complied with the ethical code of Universiti Sains Malaysia Review Board.

3.3 EXPERIMENTAL SETUP

This cross sectional study is descriptive in nature with an experimental design. The independent variables of interest are aerobic variables including VO_{2max}, heart rate, respiratory exchange ratio (RER) and lactate threshold; anaerobic variables are peak power and average power; and biomechanical variables are stroke rate, stroke length, angles of hip and knee and drive to recovery phase ratio; finally physical characteristics variables are age, sex, weight, height and percentage of body fat. Dependent variable is the duration taken to complete 2000m rowing on slide ergometer. These variables were measured throughout three different physiological testing procedures which are 2km time trial test, Wingate anaerobic test and 5 x 4 minutes endurance test. Before these tests, the weight, height and percentage of body fat were obtained from each participants. Extra care has been taken in reducing the circadian effect on physiological data by performing the experiments at the same time of a day with at least 48 hours interval between experiments.

The area of this study involves biomechanics and exercise physiology. Experiments were carried out on a Concept 2 model E ergometer (Morrisville, USA) (Figure 3.1). The slides system consists of a pair of rails that can be attached to the ergometer to simulate on-water rowing mechanics. Based on Kane, (2008), drag factor was manually adjusted according to body weight to match the resistance effect of rowing on water. The drag factor was adapted from Australian Institute of Sport and Australian Rowing (Table 3). The data on heart rate, power output, time and distance covered was provided during the test through an attached display on the ergometer.

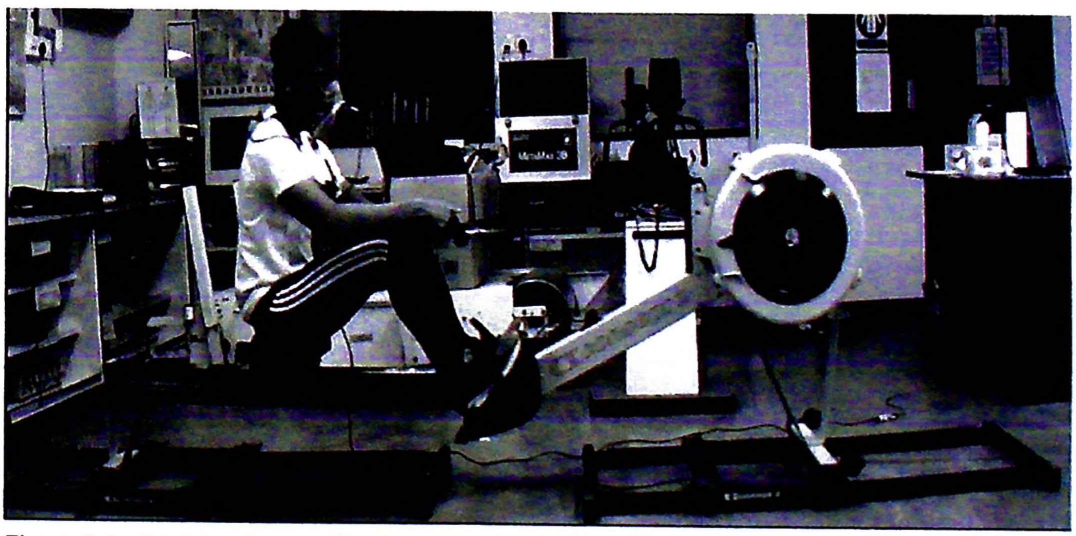

Figure 3.1 : Concept 2 model E ergometer (Morrisville, USA) with slides

A camera was positioned on sagittal plane to measure the motion. Kinematic data were analysed using Siliconcoach Pro 8 (Dunedin, New Zealand) software. Figure 3.2 showed the measurement of knee and hip angle at catch and finish position using Siliconcoach software. The duration of drive and recovery phase for each cycle were taken. The ratio of drive to recovery duration (D:R) was obtained by dividing drive duration to recovery duration.

A : finish position

B : Catch position

Figure 3.2 : Measuring knee and hip angle using Siliconcoach Pro 8 software

Table 3 : Ergometer drag factor setting

Category	Drag Factor
Junior female	95
Lightweight female	95
Heavyweight female	105
Junior male	105
Lightweight male	105
Heavyweight male	115

Figure 3.3 : Cortex Metamax3B portable metabolic system (MM3B, Leipzig, Germany)

Figure 3.4 : Polar (Electro Oy, Finland) heart rate monitor

Cortex MetaMax3B portable metabolic system (MM3B, Leipzig, Germany) (Figure 3.3) was used to measure the metabolic variables such as oxygen consumption (VO_2), carbon dioxide production (VCO_2), respiratory exchange ratio (RER) and expired ventilation (VE). This system was prove by Vogler *et al.*, (2015) to be reliable and provide valid measurements during rowing physiological tests. The measurements of breath-by-breath using MetaMax3B were averaged over 30 s interval. Polar (Electro Oy, Finland) (Figure 3.4) was used to measure the heart rate. A short wave transmitter in the form of a narrow belt worn around the chest which read the data into the MetaMax 3B system software

Blood lactate concentration ([La-]b) was measured at specific times according to different physiological test. Finger prick was conducted by a trained technologist using Accu-Chek Safe T Pro Plus disposable lancets (Mannheim, Germany). Blood lactate concentration then was measured by Accutrend Plus system (Mannheim, Germany) (Figure 3.5).

Figure 3.5 : Blood lactate analyser by Accutrend Plus system (Mannheim, Germany).